

JC662 U.S. PTO  
08/23/99

PATENT  
Attorney Docket No.: CSII260-1

- ☐ NEW PATENT APPLICATION  
☒ CONTINUATION  
☐ DIVISIONAL  
☐ CONTINUATION-IN-PART  
☐ CONTINUED PROSECUTION APPLICATION

ASSISTANT COMMISSIONER  
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*Rebecca J. Morrison*  
Rebecca J. Morrison August 23, 1999  
Date

JC662 U.S. PTO  
09/379239  
08/23/99

Sir:

Transmitted herewith for filing in the continuation patent application of:

Inventor: Jean Henry Albert Scholten, et al.  
For: VARIABLE AIR VOLUME ENVIRONMENTAL MANAGEMENT SYSTEM  
INCLUDING A FUZZY LOGIC CONTROL SYSTEM

Enclosed are:

1. ☒ 65 pages of the Specification, claims, 1 page of the Abstract
2. ☒ 10 sheets of formal drawings
3. ☒ Assent of Assignee to Reissue
4. ☒ A Reissue Declaration by Inventors and Power of Attorney
5. ☒ Request for Abstract of Title and Offer to Surrender

FULL NAME OF FIRST INVENTOR	Jean H. A. Scholten		
CITIZENSHIP			
POST OFFICE ADDRESS		Perth, Australia	
FULL NAME OF SECOND INVENTOR	Anno J. Scholten		
CITIZENSHIP			
POST OFFICE ADDRESS		Perth, Australia	

6. ☒ Cancel in this application original claims 2, 6, 7, 9-14, 16, 20, 21, 23-28, 30, 34, 35, and 37-42 of the prior application before calculating the filing fee.
7. ☒ A preliminary amendment is enclosed

The filing fee has been calculated as shown below:

	Number Filed		Number Extra		Rate			Fee	
					Small Entity	Other Entity		Small Entity	Other Entity
Total Claims	30	=	10	X	\$9	\$18	=		\$ 180.00
Independent Claims	5	=	2	X	\$39	\$78	=		\$ 156.00
Multiple Dependent Claims Presented. ___ Yes ___X___ No					\$130	\$260			
BASIC FEE					\$380	\$760		\$	\$ 760.00
					TOTAL FEE			\$	\$1,096.00

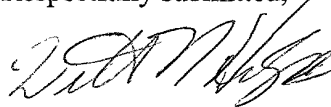
8. ☒ Please charge my Deposit Account No. 50-0456 the amount of \$1,096.00.
9. ☒ The Assistant Commissioner is hereby authorized to charge payment of the following fees associated with this communication or credit any overpayment to Deposit Account No. 50-0456.
- Any additional filing fees required under 37 C.F.R. 1.16.
  - Any patent application processing fees under 37 C.F.R. 1.17.
10. ☒ Amend the specification by inserting before the first paragraph on page 1:  
This application is a continuation of application Serial No. 08/932,652 filed on September 18, 1997, now pending, the entire contents of which are hereby incorporated by reference herein.
11. ☐ A verified statement claiming small entity status was filed in parent application Serial No. \_\_\_\_\_, filed \_\_\_\_\_, and such status is still proper.
12. ☒ The prior application is assigned of record to EMS Control Systems International.
13. ☒ The power of attorney in the prior application is to William N. Hulsey Registration No. 33,402; and Steven R. Sprinkle, Registration No. 40,825.
14. ☒ Please transfer the drawings from the prior application to the new application.
15. ☒ A true copy of the prior application as filed is enclosed, including the Reissue Declaration by Inventors and Power of Attorney filed in parent application.
16. ☐ Information Disclosure Statement(s) filed in the prior application under 37 C.F.R. § 1.97 is(are) hereby made of record, (copy of 1449 is enclosed herewith).
17. ☐ Also enclosed are:

Address all future communications to:

William N. Hulsey III  
GRAY CARY WARE ▲ FREIDENRICH LLP  
100 Congress Avenue, Suite 1440  
Austin, Texas 78701  
Telephone: 512-457-7040  
Facsimile: 512-457-7070

The undersigned states that the enclosed application papers comprise a true copy of the prior application as filed.

Respectfully submitted,



Date: August 23, 1999

William N. Hulsey III  
Attorney for Applicant  
Registration No. 33,402

GRAY CARY WARE ▲ FREIDENRICH LLP  
100 Congress Avenue, Suite 1440  
Austin, Texas 78701  
Telephone: 512-457-7040  
Facsimile: 512-457-7070

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of: Jean Henry Albert Scholten, et al.  
Serial No.: Unknown  
Filing Date: August 23, 1999  
Group Art Unit: 3744  
Examiner: Unknown  
Title: VARIABLE AIR VOLUME ENVIRONMENTAL  
MANAGEMENT SYSTEM INCLUDING A FUZZY  
LOGIC CONTROL SYSTEM

Honorable Asst. Commissioner  
of Patents  
Washington, D.C. 20231

I hereby certify that this correspondence is  
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Patents, Washington, D.C. 20231, on August  
23, 1999.  
*Rebecca J. Morrison*  
Rebecca J. Morrison

Dear Sir:

PRELIMINARY AMENDMENT

Please enter this preliminary amendment prior to  
examining the continuation application filed August 23, 1999  
under section 1.53(b) as a continuing application from patent  
application serial number 08/932,652.

Please amend the above-identified Application as follows:

IN THE SPECIFICATION

On page 2, line 1, please insert before the heading  
"BACKGROUND OF THE INVENTION" the following heading and  
paragraph:

--RELATED APPLICATIONS

This application is a continuation of, and claims priority from, U.S. Patent Application Serial No. 08/932,652, filed on September 18, 1997, now pending, the entire contents of which are hereby incorporated by reference herein.--

IN THE CLAIMS:

Note that all of the Claims pending in the application have been included, whether amended or not, to aid Examiner in reviewing the Amendment.

1. A controller for a variable air volume terminal, of a variable air volume air conditioning system, comprising:

temperature sensing circuitry for generating a temperature process value;

setpoint determining circuitry for establishing a temperature setpoint;

airflow signal circuitry for generating an airflow setpoint in response to said temperature process value and said temperature setpoint;

flow sensing circuitry for generating a flow process value in response to a predetermined set of flow sensing inputs; and

damper control circuitry for generating a damper motor operation signal to control the damper motor in response to said flow process value and said airflow setpoint, said damper control circuitry comprising a fuzzy logic control mechanism

for implementing a set of fuzzy logic rule-based instructions in generating said damper motor operating signal.

2. (CANCEL)

3. The controller of Claim 1, wherein said temperature sensing circuitry, said setpoint determining circuitry, said airflow signal circuitry, and said flow sensing circuitry operate under an open protocol that permits system-wide control and monitoring of said controller within said variable air volume air conditioning system.

4. The controller of Claim 1, wherein said temperature sensing circuitry, said setpoint determining circuitry, said airflow signal circuitry, and said flow sensing circuitry are associated to permit pressure dependent operation of said controller.

5. The controller of Claim 1, wherein said temperature sensing circuitry, said setpoint determining circuitry, said airflow signal circuitry, and said flow sensing circuitry are associated to permit pressure independent operation of said controller.

6. (CANCEL)

7. (CANCEL)

8. The controller of Claim 1, further comprising circuitry for permitting remote control of said controller for controlling operation of said variable air volume terminal.

9. (CANCEL)

10. (CANCEL)

11. (CANCEL)

12. (CANCEL)

13. (CANCEL)

14. (CANCEL)

15. A method for controlling a variable air volume terminal, having a damper and a damper motor, comprising the steps of:

generating a temperature process value using temperature sensing circuitry;

establishing a temperature setpoint using setpoint determining circuitry;

generating an airflow setpoint in response to said temperature process value and said temperature setpoint using airflow signal circuitry;

operating said variable air volume terminal in a warm-up mode of operation

generating a flow process value in response to a predetermined set of flow sensing inputs using flow sensing circuitry; and

generating a damper motor operation signal using damper control circuitry to control the damper motor in response to said flow process value and said airflow setpoint, said damper motor operation signal generating step further comprising the step of implementing a set of fuzzy logic rule-based instructions in generating said damper motor operating signal.

16. (CANCEL)

17. The method of Claim 15, further comprising the step of operating said temperature sensing circuitry, said set point determining circuitry, said air flow signal circuitry, and said flow sensing circuitry under an open protocol that permits system-wide control and monitoring of said controller within said variable air volume air conditioning system.

18. The method of Claim 15, further comprising the step of associating said temperature sensing circuitry, said set point determining circuitry, said air flow signal circuitry, and said flow sensing circuitry to permit pressure dependent operation of said controller.

19. The method of Claim 15, further comprising the step of associating said temperature sensing circuitry, said set point determining circuitry, said air flow signal circuitry,



and said flow sensing circuitry to permit pressure independent operation of said controller.

20. (CANCEL)

21. (CANCEL)

22. The method of Claim 15, further comprising circuitry for permitting remote control of said controller for controlling operation of said variable air volume terminal.

23. (CANCEL)

24. (CANCEL)

25. (CANCEL)

26. (CANCEL)

27. (CANCEL)

28. (CANCEL)

29. A variable air volume air conditioning system, comprising:

a controller for a variable air volume terminal;

a variable air volume terminal comprising a damper, a damper motor associated to move said damper, and a terminal

controller for controlling operation of said damper motor,  
said terminal controller comprising:

temperature sensing circuitry for generating a  
temperature process value;

setpoint determining circuitry for establishing a  
temperature setpoint;

airflow signal circuitry for generating an airflow  
setpoint in response to said temperature process value and  
said temperature setpoint;

flow sensing circuitry for generating a flow process  
value in response to a predetermined set of flow sensing  
inputs; and

damper control circuitry for generating a damper  
motor operation signal to control the damper motor in response  
to said flow process value and said airflow setpoint, said  
damper control circuitry comprising a fuzzy logic control  
mechanism for implementing a set of fuzzy logic rule-based  
instructions in generating said damper motor operating signal.

30. (CANCEL)

31. The system of Claim 29, wherein said temperature  
sensing circuitry, said setpoint determining circuitry, said  
airflow signal circuitry, and said flow sensing circuitry  
operate under an open protocol that permits system-wide  
control and monitoring of said controller within said variable  
air volume air conditioning system.

32. The system of Claim 29, wherein said temperature sensing circuitry, said setpoint determining circuitry, said airflow signal circuitry, and said flow sensing circuitry are associated to permit pressure dependent operation of said controller.

33. The system of Claim 29, wherein said temperature sensing circuitry, said set point determining circuitry, said air flow signal circuitry, and said flow sensing circuitry, are associated to permit pressure independent operation of said controller.

34. (CANCEL)

35. (CANCEL)

36. The system of Claim 29, further comprising circuitry for permitting remote control of said controller for controlling operation of said variable air volume terminal.

37. (CANCEL)

38. (CANCEL)

39. (CANCEL)

40. (CANCEL)

41. (CANCEL)

42. (CANCEL)

43. A controller for an environmental control system, comprising:

temperature circuitry for receiving a signal representing a temperature process value;

setpoint circuitry for receiving a signal representing a temperature setpoint;

demand signal generating circuitry for generating a demand signal in response to said temperature process value and said temperature setpoint;

flow sensing circuitry for generating a flow process value in response to a predetermined set of flow sensing inputs; and

flow medium control signal generating circuitry for generating a flow medium control signal to control an actuator in response to said flow process value and said demand signal, said flow medium control signal generating circuitry comprising a fuzzy logic control mechanism for implementing a set of fuzzy logic rule-based instructions in generating said flow medium control signal.

44. The controller of Claim 43 wherein the flow medium control signal generating circuitry is operable to generate a flow medium control signal to an actuator, such that the flow medium control signal represents an offset, and wherein said

offset represents an incremental move of the actuator.

45. The controller of Claim 43 wherein the flow medium control signal generating circuitry is operable to generate a flow medium control signal to an actuator, such that the flow medium control signal represents instructions to the actuator to move the actuator from a first position to a second position.

46. A method for controlling an environment, comprising the steps of:

receiving a signal representing a temperature process value;

receiving a signal representing a temperature setpoint;  
generating a demand signal in response to said temperature process value and said temperature setpoint;

generating a flow process value in response to a Predetermined set of flow sensing inputs; and

generating a flow medium control signal to control an actuator in response to said flow process value and said demand signal, said flow medium control signal generating step further comprising the step implementing a set of fuzzy logic rule-based instructions in generating said flow medium control signal.

47. The method of Claim 46 wherein the flow medium control signal generating step comprises generating a flow medium control signal to an actuator, such that the flow

medium control signal represents an offset, and wherein said offset represents an incremental move of the actuator.

48. The method of Claim 46 wherein the flow medium control signal generating step comprises generating a flow medium control signal to an actuator, such that the flow medium control signal represents instructions to the actuator to move the actuator from a first position to a second position.

79. (New) The controller of Claim 43, wherein the controller is a variable air volume terminal controller and wherein the environmental control system is a variable air volume air conditioning system.

80. (New) The controller of Claim 43, wherein said actuator is a control valve actuator for adjusting the flow of water through a heating coil.

81. (New) The controller of Claim 43, wherein said temperature circuitry, said setpoint circuitry, said demand signal generating circuitry, and said flow sensing circuitry operate under an open protocol that permits system-wide control and monitoring of the controller within said environmental control system.

82. (New) The controller of Claim 43, wherein said temperature circuitry, said setpoint circuitry, said demand signal generating circuitry, and said flow sensing circuitry are associated to permit pressure dependent operation of the controller.

83. (New) The controller of Claim 43, wherein said temperature circuitry, said setpoint circuitry, said demand signal generating circuitry, and said flow sensing circuitry are associated to permit pressure independent operation of said controller.

84. (New) The controller of Claim 43, further comprising Hall Effect circuitry for identifying and controlling operation of said temperature circuitry, said setpoint circuitry, said demand signal generating circuitry, said flow sensing circuitry, and said flow medium control signal generating circuitry upon placing a predetermined magnet device proximate said Hall Effect circuitry.

85. (New) The controller of Claim 43, further comprising a shield surrounding said flow sensing circuitry for limiting affects of temperature variations on operation of said flow sensing circuitry.

86. (New) The method of Claim 46, wherein the environmental control system is a variable air volume air conditioning system.

87. (New) The method of Claim 46, wherein said actuator is a control valve actuator for adjusting the flow of water through a heating coil.

REMARKS

Applicants appreciate the time taken by the Examiner to review Applicants' present Application and respectfully request examination and favorable action in this case.

To advance prosecution of this case, Applicants address below the Examiner's rejections from the Official Action mailed May 21, 1999 as part of the prosecution of this continuation application's parent application, U.S. Patent Application Serial No. 08/932,652, filed on September 18, 1997.

This preliminary amendment also adds additional claims to more fully claim applicant's invention.

Rejections under 35 U.S.C. § 103(a)

The Examiner rejected Claims 1, 4, 15, 18, 19, 29, 32, 43, 45, 46, 48, 79, 82 and 86 under 35 U.S.C. § 103(a) as being unpatentable over U.S. Patent No. 4,928,840, issued to Nurczyk, in view of European Patent No. 0 248 380 issued to Heckenbach, U.S. Patent No. 5,251,124, issued to Matsunaga, and U.S. Patent No. 5,156,013, issued to Arima, et al.

Applicants respectfully submit that neither Nurczyk, Heckenbach, Matsunaga, nor Arima teach, suggest, or make obvious the combination of a fuzzy logic controller, such as



that disclosed in Matsunaga or Arima, with a Variable Air Volume terminal, as disclosed in Nurczyk, and the plural pressure sensors of Heckenbach. Absent such suggestion, there would be no reason why one skilled in the art, faced with Applicants' problem of creating a simpler and more effectively operable Variable Air Volume("VAV") terminal controller and VAV system, and having no prior knowledge of Applicants' claimed structure, would consult the combination of references suggested by the Examiner.

Matsunaga discloses a fuzzy logic controller meant to improve fuzzy logic control of an object in a steady-state mode of operation, but does not teach or suggest the use of such a controller for a VAV system. Matsunaga, in fact, discloses an improved fuzzy logic controller, but does not disclose or suggest a particular use for such a controller. Similarly, Arima teaches the use of a fuzzy logic controller, but only for use with an absorption refrigerator. Applicants respectfully submit that it is not obvious or conventional to use a fuzzy logic controller, such as disclosed in Matsunaga or Arima, in a VAV system to implement a comparison of a setpoint and a measured variable to generate a control signal, such as a damper control signal. At least in the case of VAV systems, PID control algorithms are the prior art and it is not obvious to combine the above references to apply fuzzy logic control algorithms to VAV systems. One skilled in the art of VAV systems and their associated control methods would therefore not be likely to use either Matsunaga or Arima, alone or in combination with any other reference, including

Nurczyk or Heckenbach, to attempt to solve the problem solved by Applicants.

Applicants respectfully submit that for the reasons given above Claims 1, 15, 29, 43, and 46 meet the requirements of § 103(a). Claim 4 depends from Claim 1 and contains, by virtue of its dependency, all the limitations of Claim 1. Claims 18 and 19 depend from Claim 15, and contain, by virtue of their dependency, all the limitations of Claim 15. Claim 32 depends from Claim 29, and contains, by virtue of its dependency, all the limitations of Claim 29. Claims 45, 79, and 82 depend from Claim 43, and contain, by virtue of their dependency, all the limitations of Claim 43. Claims 48 and 86 depend from Claim 46, and contain, by virtue of their dependency, all the limitations of Claim 46. Accordingly, Applicants respectfully submit that Claims 4, 18, 19, 32, 45, 48, 79, 82 and 86 also meet the requirements of § 103(a). Applicants therefore respectfully request the Examiner to reconsider and withdraw the rejections and allow Claims 1, 4, 15, 18, 19, 29, 32, 43, 45, 46, 48, 79, 82 and 86.

The Examiner rejected Claims 3, 8, 17, 22, 31, 36 and 81 under 35 U.S.C. § 103(a) as being unpatentable over U.S. Patent No. 4,928,840, issued to Nurczyk, in view of European Patent No. 0 248 380 issued to Heckenbach, U.S. Patent No. 5,251,124, issued to Matsunaga, and U.S. Patent No. 5,156,013, issued to Arima, et al, and further in view of U.S. Patent No. 4,969,508, issued to Tate, et al, which shows remote and local control of an air terminal.

Claims 3 and 8 depend from Claim 1, and contain, by

virtue of their dependency, all the limitations of Claim 1. Claims 17 and 22 depend from Claim 15, and contain, by virtue of their dependency, all the limitations of Claim 15. Claims 31 and 36 depend from Claim 29, and contain, by virtue of their dependency, all the limitations of Claim 29. Claim 81 depends from Claim 43, and contains, by virtue of its dependency, all the limitations of Claim 43. For the same reasons as discussed above, Applicants respectfully submit that Claims 1, 15, 29, and 43 meet the requirements of § 103(a), and therefore Claims 3, 8, 17, 22, 31, 36 and 81 also meet the requirements of § 103(a).

Furthermore, Tate discloses a portable wireless remote control unit that allows a room occupant to control the environment in his or her individual room (col. 1, lines 53-68 and col. 3, line 53-col. 4, line 11). Applicants' invention, however, teaches a method for system-wide remote control of a VAV system using a high-speed, open protocol within a Local Operating Network (LON®) (page 7, lines 16-26, page 11, lines 9-12, and page 11, line 26-page 12, line 12). Applicants' invention, unlike Tate, is therefore capable of remote control through a network connection, as opposed to the handheld infrared wireless remote control of Tate. Even further, Applicants' invention allows remote control of the entire VAV system, and not just a single occupant's room. Accordingly, Applicants respectfully request the Examiner to reconsider and withdraw the rejections and allow Claims 3, 8, 17, 22, 31, 36 and 81.

The Examiner rejected Claims 5, 33, and 83 under 35

U.S.C. § 103(a) as being unpatentable over the art as applied to Claim 1 (see above) and further in view of Official notice "that it is well known to measure air flow by using a heated thermistor or an air turbine. . . ." Applicants' respectfully submit that neither of Claims 5, 33, or 83 recite the limitation of using a heated thermistor or an air turbine to measure air flow. Furthermore, Claim 5 depends from Claim 1, and contains, by virtue of its dependency, all the limitations of Claim 1. Claim 33 depends from Claim 29, and contains, by virtue of its dependency, all the limitations of Claim 29. Claim 83 depends from Claim 43, and contains, by virtue of its dependency, all the limitations of Claim 43. For the same reasons as discussed above, Applicants respectfully submit that Claims 1, 29, and 43 meet the requirements of § 103(a), and therefore Claims 5, 33 and 83 also meet the requirements of § 103(a)

Rejections under 35 U.S.C. § 112

Claims 43-48, 80, 84, 85, and 87 stand rejected under 35 U.S.C. § 112, first paragraph, as containing subject matter which was not described in the specification in such a way as to reasonably convey to one skilled in the relevant art that the inventors, at the time the application was filed, had possession of the claimed invention. The Examiner states that "[t]he original disclosure does not support fuzzy logic control of liquid valves, hall effect circuitry (claim 84) and a shield for the flow sensor (claim 85)."

Applicants submit that Claims 43-48, 80, and 87 are

supported by the specification of the original case as filed. The original specification teaches a controller that can be used to control a VAV terminal. As part of controlling a VAV terminal that could be part of a VAV air conditioning system, or other environmental management system, the controller disclosed in the present Application can also control an auxiliary fan, first and second heaters, and a hot water coil flow control valve (page 13, lines 18-20, page 15, lines 4-7, and page 20, lines 3-17).

The control scheme disclosed in Applicants' present Application is intended ultimately to be used to control an air medium. However, to control the air medium, the control scheme also can be used to control alternative mediums, such as hot water in a coil, that directly affect the air medium. Even further, the ability to control an additional medium other than air, which in turn directly affects the air medium, is an integral embodiment of Applicants' invention.

In a VAV terminal controller embodiment, the controller disclosed by Applicants' can be used to control the temperatures in different parts of an environment by modulating the flow of air having a constant temperature. However, an integral part of controlling the flow of air includes the ability to maintain the desired air temperature to begin with. Controlling the temperature of the air by, for example, controlling the valve that controls the flow of hot water to a heating coil, is therefore not only within the scope of Applicants' invention as disclosed, but clearly an important feature of Applicants' invention.

Claims 84 and 85 are also supported by the specification of the original case as filed. The use of Hall Effect circuitry, in combination with a magnet, as recited in Claim 84, is supported by the specification as originally filed at page 46, lines 10-19. Similarly, the use of a shield surrounding the flow sensing circuitry, as recited in Claim 85, is supported by the specification at page 47, line 16-page 48, line 7.

Applicants therefore respectfully request the Examiner withdraw the rejections and allow Claims 43-48, 80, 84, 85, and 87.

CONCLUSION

Applicants appreciate the Examiner's efforts to review this case. Applicants have made an earnest attempt to place this case in condition for allowance and request continued examination and allowance of the Application. For the foregoing reasons and for other reasons clearly apparent, Applicants respectfully request full allowance of Claims 1, 3-5, 8, 15, 17-19, 22, 29, 31-33, 36, 43-48, and 70-78.

The Commissioner is hereby authorized to charge any fees or credit any overpayments to Deposit Account No. 50-0456 of Gray Cary Ware & Freidenrich, LLP.

Respectfully submitted,

GRAY CARY WARE ▲ FREIDENRICH LLP  
Attorneys for Applicants



William N. Hulsey III  
Reg. No. 33,402

Dated: August 23, 1999  
100 Congress Avenue  
Suite 1440  
Austin, TX 78701  
(512) 457-7040  
(512) 457-7070 (facsimile)

VARIABLE AIR VOLUME ENVIRONMENTAL MANAGEMENT  
SYSTEM INCLUDING A FUZZY LOGIC CONTROL SYSTEM

TECHNICAL FIELD OF THE INVENTION

The present invention relates to control systems for environments such as office buildings and commercial establishments, and more particular, to a variable air volume (VAV) environmental management system that integrates a fuzzy logic control system in a stand-alone package for providing all necessary functions of a VAV terminal that may be easily networked into a complex environmental management system and that uses fuzzy logic to provide precise temperature control with the minimal amount of system setup.



BACKGROUND OF THE INVENTION

A variable air volume (VAV) environmental management or air conditioning system modulates the amount of air that flows to different offices or locations within an environment such as an office building or other dwelling structure where numerous people live or work. By maintaining constant the temperature that flows through dampers of the air conditioning system and, instead adjusting the position of the damper or the volume of air that flows through the damper to the various locations within the environment, is possible to more efficiently and effectively address the comfort needs of different locations within the environment.

Known VAV controllers are large remote electronic boxes or cabinets that electrically connect to actuator motors that control the position of the dampers of the environmental control system. These controllers are often, for example, pneumatic controllers or electrical controllers that respond to temperature input to adjust the position of the damper in response to the sensed temperature of the various locations. These pneumatic drives or electrical systems are generally not inter-related from one location to another within the environment. As a result, compensating for temperature differences in one location frequently generates air flow problems in other locations within the environment. The

air conditioning system, in these instances, operates in less than an ideal mode.

In recent years, microprocessors have been used to improve the efficiency of controlling various locations within the office or environment. These microprocessors attempt to relate locations within the environment to one another by using an air velocity pickup probe input. The air velocity pickup probe provides an input to the microprocessor that permits the microprocessor to compensate for drops in air flow to one location that arise from an increase in air flow to another location. In other words, microprocessor-based VAV terminal controllers attempt to improve the overall operation of the environmental management system by compensating for drops in air flow that occur as temperature needs or setpoints change at different locations within the environment. There are, however, significant limitations that associate with existing microprocessor-based VAV terminal controllers.

Significant limitations of existing microprocessor-based VAV terminal controllers are, for example, that the systems are bulky and include large printed circuit boards that mount within separate controller chassis. These known systems include motors and wires to control the damper motor in the environmental control system. In addition, existing microprocessor-based controllers at best use local area network technology for system data

communication. Local area networks, however, are not designed for communicating control system data within a control system architecture. These local area networks inefficiently communicate temperature, pressure and other  
5 variable values from one location to another and to a central file server.

Another limitation associated with existing microprocessor-based VAV terminal controllers is the use of complicated instruction sets for generating the  
10 desired damper actuator control signal. For example, even the most efficient VAV terminal controllers use a control algorithm known as a proportional integral differential (PID) algorithm to drive the damper motor. The PID algorithm itself is complex and requires  
15 significant computational resources to generate the desired damper motor operating signal. The complexity of the PID algorithm requires significant setup time for each of the locations within the office or commercial environment. The setup time and inherent complexity of  
20 the algorithm makes such systems prone to error and highly susceptible to less than optimal performance.

Consequently, there is a need for an improved microprocessor-based VAV terminal controller that avoids the space requirements and separate bulky controller  
25 circuit chassis of existing microprocessor-based VAV terminal controllers.

There is a need for an improved microprocessor-based VAV terminal controller that is more effectively operable with other aspects of the environmental management system as well as with the VAV air conditioning system within the environmental management system.

There is yet the need for an improved VAV terminal controller that is simple to setup and use and that avoids the complexity of existing microprocessor-based controllers that use PID control instructions or other similarly complicated instructions to adjust for the differences in air flow within the air conditioning portion of the environmental control system.

SUMMARY OF THE INVENTION

5 The present invention, accordingly, provides an improved VAV terminal controller that overcomes limitations and disadvantages of existing VAV terminal  
10 controllers and that controls dampers at locations within a VAV air conditioning system and that integrates a fuzzy logic control system to more efficiently communicate with the associated environmental control system and that in a stand-alone package, attaches to the damper actuator motor.

15 The improved VAV terminal controller, according to one aspect of the invention, includes temperature sensing circuitry for generating a temperature process value. Temperature setpoint determining circuitry establishes a temperature setpoint. Air flow signal circuitry  
20 generates an air flow setpoint in response to the temperature process value and the temperature setpoint. Airflow sensing circuitry generates the airflow process value in response to a predetermined set of airflow sensing inputs. Damper control circuitry generates a damper motor operation signal to control the damper actuator motor in response to the airflow process value and the airflow setpoint. The damper control circuitry  
25 includes a fuzzy logic control mechanism for implementing a set of fuzzy logic or rule-based instructions in generating the damper actuator motor operating signal.

A technical advantage of the present invention is that it provides in a single module a control device for operating the damper actuator motor of a VAV air conditioning system. The present invention is so compact  
5 that it may be positioned on the damper actuator motor itself, instead of at a remote site in a separate control circuitry chassis. The present invention incorporates advanced packaging technology to eliminate the need for a large printed circuit board chassis that conventional VAV  
10 terminal controllers require. A VAV air conditioning system that employs the present invention, therefore, is easier to install, operate, and maintain than systems that use conventional microprocessor-based VAV terminal controllers.

Another technical advantage of the present invention  
15 is that it provides a local, stand-alone control mode or a network control mode using a high-speed, open protocol within a local operating network (LON®). The protocol that the present invention uses more effectively  
20 communicates temperature values, pressure values, and other values and parameters than do systems that employ protocols of local area networks (LANs). The present invention includes operating firmware in a single integrated circuit device that requires no interfaces or  
25 protocol converters and that may be completely inter-operable with other (LON®) systems.

A further technical advantage of the present invention is that it implements a fuzzy logic or rule-based control instruction set to more efficiently generate the desired damper motor operating signals.

5 Using fuzzy logic control instructions, the present invention ensures precise and efficient operation that requires only a minimal effort to program and commission each VAV terminal within the VAV air conditioning system.

Additional technical advantages that the present invention possesses over existing microprocessor-based VAV terminal controllers include pressure dependent or pressure independent control modes; built-in fire and warm-up operating modes; and an optional integral remote environmental monitoring (REM) sensor. In the preferred embodiment, all setpoints may be adjustable using an optional hand-held console. The preferred embodiment is simple to install and to commission. The damper control features that the present embodiment provides include (1) automatic calibration of the damper stroke, (2) manual drive of the damper to any position within the damper strokes; and (3) automatic stop of damper control at the damper actuator motor end limits. The preferred embodiment includes an inexpensive airflow pickup sensor that may connect directly to the terminal controller and that consumes minimal amounts of power. The system of the preferred embodiment includes a totally integrated controller, flow transducer, and damper actuator as part

of the VAV terminal controller. Other features of the present invention and preferred embodiment will become apparent upon reading the following detailed description of the illustrative embodiment in conjunction with an understanding of the associated drawings.

5

662200 662200 662200



BRIEF DESCRIPTION OF THE DRAWINGS

The invention and its modes of use and advantages are best understood by reference to the following description of illustrative embodiments, when read in  
5 conjunction with the accompanying drawings, wherein:

FIGURE 1 shows one embodiment of the VAV terminal controller of the present invention;

FIGURE 2 illustrates the temperature and airflow control characteristic of the present embodiment;

10 FIGURES 3 and 4 provide illustrative flow diagrams of the functions of the present embodiment;

FIGURES 5 and 6 illustrate one embodiment of the fuzzy logic weight matrix and parameter ranges, respectively, for implementing the control instructions  
15 of the present invention; and

FIGURES 7, 8, and 9 illustrate various aspects of the electronic circuitry for implementing the present embodiment of the invention.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The illustrative embodiments of the present invention are best understood by referring to the FIGURES wherein like numerals are used for like and corresponding parts of the various components.

With a room temperature sensor and setpoint adjust, the VAV terminal controller of the present embodiment provides a complete stand-alone controller for any type of VAV terminal. When networked on an open protocol local operating network (LON), the VAV terminal controller of the present embodiment provides system-wide control, monitoring, and optimization. The present embodiment may include an integral flow transducer, damper actuator, feedback potentiometer for either pressure independent or pressure dependent control modes. The VAV terminal controller of the present embodiment also provides an output for either single-stage electric reheat, modulated electric reheat, or modulated hydronic reheat. The complete controller, including the air flow transducer, may be housed entirely outside the casing of the damper motor. This makes the complete device of the present embodiment sufficiently small so that it can be mounted directly onto the damper shaft. Moreover, installing the present embodiment requires a minimal amount of effort, time, and expense.

The VAV terminal controller of the present embodiment includes a Neuron® integrated circuit that

provides a complete and embedded interface to the LON®.  
The LON® includes intelligent devices or nodes that  
connect by one or more communications devices and  
communicate with one another using a common protocol.

5 The various locations of a VAV air conditioning system  
that uses the preferred embodiment may be programmed to  
send messages to one another in response to various  
conditions and to take action in response to messages  
that they receive. The VAV terminal controller of the  
10 present embodiment, therefore, is compatible with the  
protocol for the local operating network. This provides  
for inter-operability with other LON-based systems. By  
using fuzzy logic to maintain the desired air flow, the  
VAV terminal controller of the present embodiment ensures  
15 precise and efficient operation and only requires minimal  
effort to program and commission each VAV terminal.

Referring to FIGURE 1, there appears VAV terminal  
controller 10 of the present embodiment that includes  
terminal controller chassis 12 that receives line 14 and  
20 controller switch 16. In chassis 12, airflow pickup  
probe 18 connects to provide an input relating to the air  
flow of the VAV terminal damper. Line 14 connects at  
connector 22 to a number of electrical circuits. For  
example, through connector 22, line 14 connects to 24  
25 volt AC supply line 24, local operating network  
connection 26, room temperature sensor connection 28, and  
electrical heater element line 30. A 24-volt AC supply

line 24 provides the necessary power supply to VAV terminal controller 10. Local operating network line 26 communicates with local operating network to communicate with other nodes and servers on the associated network.

5 Room temperature sensor 32 connects to line 14 through  
line 28. Through line 30, relay 34 connects to  
electrical heater element 36.

The inputs to VAV terminal controller 10 include a temperature sensor with a 0.05°C resolution. An airflow transducer within team VAV controller 10 is integral to the circuit. Position of the damper motor is provided by an integral feedback potentiometer. Service switch 16 permits limited local control of VAV terminal controller 10. In addition, three user-configured inputs, either discrete or 0- to 5-volt analog inputs are possible. With these inputs, VAV terminal controller 10 provides three user-configured outputs that are either discrete digital or pulse-width modulated. The outputs can be used for secondary fan, electric heating element, or hydronic VAV control. The damper actuator may be an integral motor output. In addition, the present embodiment may include a status LED to indicate the operation of VAV terminal controller 10. Communication links in the preferred embodiment include a local operating network (LONTalk®) RS485 communication line capable of communicating at a rate of 78 kbs. In addition, the present embodiment provides a LONTalk

twisted pair capable of communicating at a rate of  
1.2 mbs as an optional communications sensor.

VAV terminal controller 10 is compact and may be  
positioned on the damper actuator itself. An important  
5 aspect of VAV terminal controller 10 that makes this  
possible is the termination of field connections for  
inputs such as room temperature sensor 32, power input  
24, LON® input 26, and heater element 36 input 30,  
through a wide range of different options that plug into  
10 chassis 12. For example, these terminal connections use  
simple multicore flying leads with no terminal  
connections, as well as multicore flying leads that  
terminate with inexpensive screw-down terminals.  
Multicore flying lead terminals are also used on the VAV  
15 terminal controller 10 printed circuit board (see FIGURE  
9, below) with an on-board fuse and screw-down terminals.  
In addition, VAV terminal controller 10 uses a printed  
circuit board that can be mounted on top of the VAV  
terminal and that has an on-board fuse, an LED status  
20 indication, and screw-down terminals. The combination of  
packaging innovation with improved connections that VAV  
terminal controller 10 provides permits exact selection  
of the type and subsequent cost of the termination  
technique for a particular VAV application.

25 FIGURE 2 provides a diagram that illustrates the  
operation of the present embodiment to control airflow of  
a VAV terminal for cooling and heating a location within

an environment that a VAV air conditioning system serves. In FIGURE 2, control diagram 40 depicts the overall strategy that VAV terminal controller 10 implements. Based on setpoint value 42, VAV terminal controller 10 will control either the associated damper actuator motor to provide cooling or a set of heaters and an auxiliary fan to provide heating. VAV terminal controller 10 may include preset default parameters that permit the controller to operate in a stand-alone mode without user intervention. The user, however, may access the process instructions within VAV terminal controller 10 to change configuration parameters via a communications channel. Therefore, the user may edit these configuration parameters if necessary.

In FIGURE 2, VAV control diagram 40 for the VAV terminal control strategy shows output axis 44 as a vertical axis plotted against a process variable (PV) axis 46. Airflow line 48 depicts the airflow that occurs through the associated damper. An understanding of VAV terminal controller 10, of the present invention may begin by first viewing airflow line 48 to the right of setpoint line 42. Below PV axis 46 appear three variable regions to the right of setpoint 42. That is, offset line 50 defines a predetermined offset from setpoint line 42 within which the VAV terminal controller has a deadband, i.e., the offset within which no cooling signal comes from VAV terminal controller 10. Furthermore,

proportional band (PB) cooling region 52 establishes the cooling band within which VAV terminal controller 10 produces an output that is proportional to the temperature difference above the point where cooling begins. Moreover, process band region 54 defines the entire range of operation for which VAV terminal controller 10 provides an output signal. That portion to the right of setpoint 42 controls the cooling of the location within the environment.

Returning to airflow line 48, to the right of setpoint 42 VAV terminal controller 10 will send an open signal to the damper motor at minimum open point 56 that causes the damper to open. Minimum open point 56 corresponds to the beginning of proportional band cooling range 52. As temperature increases above minimum open point 56, VAV terminal controller 10 will send a proportional signal to the damper motor causing it to open ever wider until maximum open point 58. At maximum open point 58, the damper is fully opened and the maximum airflow through the damper occurs. Maximum open point 58 corresponds to the outer limit of proportional band cooling range 52 which is also the upper limit of process band 54. Thus, from point 56 to point 58 in PB cooling range 52, VAV terminal controller 10 sends a proportional signal to the damper motor, causing the damper to open ever wider until point 58. Offset range 52 determines the position of point 56 at which proportional band

cooling begins. Thus, as FIGURE 2 indicates, offset may begin at setpoint 42 so that there is essentially no deadband in range to point 60. Note, however, that in the event that the beginning of proportional band cooling range 52 is at point 60, the slope of line 62 will change to a greater value. This may or may not be desirable based on the different control characteristics of the damper motor.

Also to the right of setpoint 42 is auxiliary fan operating line 64. In some VAV terminals, there is an auxiliary fan that circulates air in the location according to predetermined signal values. For example, in the event that airflow in the room falls below a certain value as indicated by line 66, the auxiliary fan will turn on. Horizontal line 68 illustrates where the minimum airflow line causes the auxiliary fan to oscillate. Any airflow below minimum airflow line 68 through the damper will cause the auxiliary fan to operate. Once airflow exceeds minimum airflow line 68, and given a predetermined deadband, operation of the auxiliary fan will begin as vertical line 71 indicates.

In summary, the cooling operations that take place when temperature in the location exceeds setpoint 42 include opening the damper so that airflow follows line 48 through minimum open point 56 and to maximum open point 58 until the maximum airflow occurs. In addition, operation of the auxiliary fan of the VAV terminal



corresponds to the signal values in operating a band that line 64 and the associated vertical lines 68 and 72 indicate.

When temperature falls below setpoint 42, VAV terminal controller 10 operates as the process regions to the left of setpoint 42 indicate in VAV terminal control diagram 40. Below PV axis 46, there are offset region 72 that relates to the operation of the auxiliary fan in the VAV terminal, offset region 74 that defines the operation band of a first heater in the VAV terminal, and offset region 76 that defines the operation band of a second heater within the VAV terminal. Proportional band 78 further describes the operation of the auxiliary fan. Proportional band 80 describes the operation of a first heater (hereinafter "HEATER1"). Proportional band 82 describes the operation of a second heater (hereinafter "HEATER2").

As airflow line 48 indicates to the left of setpoint 42, when the temperature falls below point 84 the auxiliary fan operates as line 86 indicates. The auxiliary fan will operate until temperature reaches point 88 where it will turn off as vertical line 90 indicates. Process band 78 determines the different temperatures at which the auxiliary fan on and off signals will occur. Offset region 72 establishes the setpoint 92 about which process band 78 operates.. Control of auxiliary fan may be either by a digital

signal that controls simply the auxiliary fan on and off condition, or may be through an analog or pulse width modulated (PWM) signal that variably controls the operation of the auxiliary fan. That is, as line 94 indicates, upon being turned on at point 96, the fan will operate at its minimum flowrate. As temperature increases, the pulse width modulated signal will cause an increase in the operation of the fan so that the airflow follows line 94 to a maximum level at point 86 and the reverse action when temperature subsequently decreases.

The operation of HEATER1 about setpoint 98 that offset 74 establishes is similar to the operation of the auxiliary fan about setpoint 92. At setpoint 100, HEATER1 turns on to its maximum level at point 102. Then, based upon whether the signal is invariable or pulse width modulated, signal control to HEATER1 will either follow line 104 or the constant output line to point 106 until power to HEATER1 terminates at point 108. Process band 80 controls this operation. Furthermore, if the temperature in the location continues to drop, a second heater will operate beginning at point 110 to cause HEATER2 to operate at its maximum level 112. Depending on whether variable power control or simply on/off control is imposed on HEATER1, the output of HEATER2 will follow line 114 or continue at full power until line 116 as temperature increases. HEATER2 turns off at point 108. Process band 82 controls the operation

of HEATER2 about setpoint 120 which offset 76 establishes.

Diagram 122 illustrates a further control possibility for temperature within a location that the VAV terminal maintains. For example, in some VAV terminals, hot water coils may be placed within the airflow path of the temperature control air. Flow diagram 122 illustrates the operation of the control valve for the heated water that flows through these coils. Thus, when it is desired to flow hot water through the heating coils, a DOWN signal, as indicated at point 124, will occur. As temperature increases above a process band setpoint, VAV terminal controller 10 generates an UP signal to close the hot water supply at point 126. This will terminate hot water flowing through the coils and cease heating the air through the VAV terminal.

The preferred embodiment of the invention provides the necessary control instructions that control the damper motor to move the associated damper and vary the air volume controlling temperature around setpoint 42. Circuitry and associated hardware and instructions of VAV terminal controller 10 receive three analog or digital inputs, produce three analog (PWM) or digital outputs, one temperature input, one communications or local area network (LAN) input, and internal connections to the damper actuator motor and damper position feedback

potentiometer. Each of the three inputs may be defined as being either an analog or digital input. In the analog mode, VAV terminal controller 10 converts a voltage between the range of 0 to 5 volts, in the preferred embodiment, to a value of 0 to 100%. Other conversion coefficients may be used depending on the particular application. For example, the present embodiment is designed to interface the S7000-Inet system manufactured by Control Systems International of Carrollton, Texas. Inputs enabled as digital can accept a voltage in the range between 0 and 34 volts DC with any voltage above 60% of 5 volts being taken as a state of 1 and any voltage below 40% of 5 volts being taken as a state 0. When enabled, the three inputs may also function as interlocks to a digital output stage and a fire mode input. In the preferred embodiment, AI/DI\_0 provides an interlock to digital output 1, AI/DI\_1 is the interlock to digital output 2, AI/DI\_2 is the fire mode input. The inputs are selected to be digital inputs by defining the input as DI or DA at the unit control interface (UCI). To configure the input of analog, it is possible to define the point as an analog input at the UCI.

Three outputs may be configured to operate as digital outputs or as analog (PWM) output or as floating drive output. This may be selected by defining the point as either a digital output or analog (or PWM) output at

the UCI. In a digital mode, the output can either drive the DC load of 24 volts at 200 milliamps or an AC load of 24 volts at 600 milliamps continuous (with an 8 amp surge for one cycle). The DC configuration is rated to drive  
5 RH1V relays as used in EMS RDB08 cards, manufactured by EMS Control Systems of Osborne Park, Western Australia. The AC configuration drives an AC contactor such as the AB100-A09NK, the LC1 D09 10 manufactured by  
10 Telemechanique, or the LY2 240VAC relay manufactured by OMRON directly. The AC or DC configuration, however, is to be specified at the time of manufacture for the preferred embodiment.

When the output is defined to be an analog output, the output will pulse width modulate from 0% to 100% of  
15 the user-defined pulse time. For example, for a pulse time defined as 25 seconds and an output value of 32%, an output will be ON for 8 seconds and OFF for 17 seconds. This option is useful for proportionally controlling HEATER1 and HEATER2 using a solid state relay. Again,  
20 the outputs can be manufactured as either an AC or DC drive. Two auxiliary connections exist on the connector card to provide a source voltage for driving solid state relays. When configured as a floating drive, the digital output DO\_1 acts as the open/up drive output and the  
25 digital output DO\_2 is the closed/down drive output.

The temperature sensor input connects to the two leads of a sensor operating in a current mode. For

example, the preferred embodiment connects to an AN592 sensor operating in the current mode to measure temperatures over the range of 0 to 75°C. In one embodiment, the input provides short-circuit protection.

5           Communications with VAV terminal controller 10 is through the communications connection 26. This connects to an RS485 network that uses the LONTalk protocol. All editing and monitoring of the operating conditions is via this channel. VAV terminal controller 10 in the  
10 preferred embodiment is powered by a 24 volt AC at 160 milliamps power source. VAV terminal controller 10 further provides a service switch that may be used with a hand-held console to assign a unit number to each VAV terminal controller in a VAV air conditioning system.  
15 This will permit single hand-held console control to all VAV terminal controllers in the VAV air conditioning system.

          In the present embodiment, the damper actuator is connected internally to the VAV terminal controller 10,  
20 with the UP/DOWN outputs available to the user as points. A feedback potentiometer from the damper is also internally connected to VAV terminal controller 10. This input provides information on the damper position, but is not used, in the preferred embodiment, to determine a  
25 control in the damper position. Airflow measurements are done via on-board flow sensor 18 through the air pick-up

probe. Two connections are made to the high and low pressure inputs from airflow velocity pick-up probe 18.

In the preferred embodiment, any of the input points may be placed into test and override conditions. Any of  
5 the output points may be placed into manual or event-initiated output-with-lock and override. VAV terminal controller 10 retains these operating conditions, even during a power-down cycle, until commanded otherwise.

To illustrate how the present embodiment achieves  
10 these results, reference is now made to FIGURES 3 through 6 which illustrate the inputs, outputs, and process control that the present embodiment provides. Beginning with FIGURE 3, there is provided a description of the controls of the auxiliary fan, HEATER1 and HEATER2 within  
15 the VAV terminal in response to various inputs. FIGURE 3 shows the above-described analog and digital inputs together with the analog and digital outputs to the auxiliary fan, HEATER1, and HEATER2, as appropriate.

In particular, FIGURE 3 shows block 200 that  
20 controls the operation of VAV terminal controller below setpoint 42 of FIGURE 2. Inputs to the VAV terminal controller 10 provides and includes AI/DI input 202 for a heater analog that goes to the submodule 204. In addition, AI/DI submodule 204 receives 01AIDI input 206  
25 that controls whether AI/DI module outputs analog 0 to 100% signal 208 or digital 0 or 1 signal 210. AI/DI module 214 receives AI/DI HEATER1 interlock input 212 and

02AI/DI input 216. AI/DI module 214 provides an analog output 218 or digital output 220. Heating control module 200 also receives input 222 into fire mode submodule 224. Based on 03AI/DI input 228, fire mode submodule 224 will produce either a variable or PWM output 228 or digital output 230 within heating control module 200.

Heating control module 200 of the present embodiment also receives a temperature sense signal 232 that temperature conversion submodule 234 uses to generate a temperature value. Input 04AI 236 provides an analog input to temperature conversion submodule 234.

Temperature conversion submodule 234 provides two output signals including sensor fail output 238 and temperature output 240. Temperature value 240 is input to heater module 200 at process variable (PV) 242. In the present embodiment, 00AI input 244 goes to setpoint submodule 246. Setpoint submodule 246 provides the SP input 248 to heater control module 200. Sensor fail signal 238 from temperature conversion submodule 234 provides temperature sense fail input 250 to heater control module 200.

Digital 00DO input 252 goes to on/off submodule 254 to provide on/off input 256 to heater control module 200. In addition, digital input 258 goes to fire submodule 260 to produce fire input 262. Fire input 262 goes to DR submodule 264, as does fire mode input 266 to produce fire signal 268. Fire signal 268 is used within heater



control module 200 to produce output for the auxiliary fan, the first heater, and the second heater.

Further processing within heater control module 200 includes operation of the control algorithm, and  
5 processing the input values, to produce the output control signals for the auxiliary fan, the first heater or up float control signal, as well as the down float or second heater control signal to control the amount of heating that takes place in air flowing through the VAV  
10 terminal. In particular, flow diagram 270 describes the operations for producing fan control signal output 272. Flow diagram 274 describes the operations for producing heater one or up float signal 276. Flow diagram 278 shows the instructions and the operation for producing  
15 heater two or down float control signal 280.

In fan flow diagram 270, submodule 282 performs the operation described in FIGURE 2 for the auxiliary fan of the VAV terminal within process band 78. Thus, submodule 282 receives as inputs a setpoint value 284 and a process  
20 variable input 286, together with a minimum airflow input 288. Based upon these inputs, submodule 282 will generate a signal as input 289 indicating whether or not the auxiliary fan should receive a signal to turn on. Signal 289 goes to relay 290, which may be an instruction set performing a relay function. Relay 290 also receives  
25 a fail safe (FS) value 294 and a FAIL signal flag-296. Module 290 includes a selector mechanism for selectively

receiving a 1 value at point 298, a 0 value at point 300,  
or an interrupt fail signal that FAIL signal flag 296  
reflects. Relay 302 receives input signal 292, OFF value  
signal 304 and ON/OFF input 306. In addition, in the  
event of a fire within the VAV terminal controller,  
submodule 302 receives fire input signal 308. Output  
signal 310 from relay 302 goes to PWM submodule 312. In  
addition, 01DO/AO signal 314 goes to PWM module 312 to  
indicate whether PWM module 312 should output a digital  
output or an analog output. PWM submodule 312 produces  
PWM output 316 that goes to the auxiliary fan of the VAV  
terminal as input 272.

The diagram 274 illustrates the steps that heating  
control module 200 performs in generating output 276 to  
HEATER1 for an UP FLOAT input 276. Beginning at  
submodule 320, setpoint value 98 and process variable  
value 322 go to submodule 320. Submodule 320 performs  
the steps discussed in FIGURE 2 in association with  
process band 80 about setpoint 98. Submodule 320  
provides output 324 to relay 326. Relay 326 also  
receives FS value flag 239 and FAIL flag 330 to generate  
output 328. Output 328 goes to relay 332. Relay 332  
receives OFF value input 334 and OR-gate 336 input 338.  
OR-gate 336 receives a FIRE flag input 340 and OFF flag  
input 342, as well as output 344 from relay 346. Relay  
346 generates output 344 in response to a HEATER1.  
interlock flag 348. The  $\overline{DIO}$  input 350 and the 0 input

352. Thus, relay 332 receives input 338, OFF value 334,  
and input 338 from relay 326 to produce output 354.  
Output 354 goes to PWM module 356, as does 02DOAO input  
358. The 02DOAO input 358 indicates to PWM submodule 356  
5 whether to generate an analog (PWM) or digital output.  
Thus, depending on the type of output that PWM submodule  
356 is to generate, output 276 will go to either HEATER1  
or UP float valve of the VAV terminal.

Flow diagram 278 indicates the steps that heater  
10 control module 200 performs to generate output 280 to  
HEATER2 or the DOWN float valve controller for the VAV  
terminal. Beginning at submodule 360, setpoint 120  
provides an input as does PV value 362. PV value 362 and  
setpoint 120 are processed by submodule 360 to generate  
15 output 364. Output 364 goes to submodule 366 as does  
fail safe value 368 and fail flag 370. Relay 366  
produces an output 369. Output 369 goes to relay 372, as  
does OFF value 374 and the OR-gate 376 output 378. OR-  
gate 376 receives three inputs including FIRE flag input  
20 380, OFF flag input 328, and output 384 from submodule  
386. Relay 386 receives HEATER2 interlock flag 388, DI\_1  
input 390, and 0 flag input 392. Therefore, relay 372  
takes input 369 from relay 366, OFF value 374, and output  
378 from OR-gate 376 to produce output 394 to PWM  
25 submodule 396. In summary, therefore, heater control  
module 200 produces fan input 272, HEATER1 (or UP-float)  
input 276, and HEATER2 (or DOWN float) input 280 based on

the predetermined setpoint values together with the  
actually sensed process variable values described in  
FIGURE 2. Each output that the heater control module 200  
produces is associated with a configuration table that  
defines the various operating parameters for the heating  
function of the VAV terminal.

As stated above in connection with heater control  
module 200, various operating parameters are used. The  
preferred embodiment uses the following definitions for  
the these operating parameters:

**PWM PERIOD** -- This is the total period of the output  
when it is functioning as a PWM output, or  
for operating in the floating mode it is  
the total valve time for valve operation.

**SETPOINT OFFSET** -- This is the offset of the VAV  
setpoint and defines the temperature  
around which this output operates.

**FAIL SAFE (FS) VALUE** -- This is the value this output is  
to assume should the temperature  
sensor fail (i.e., exceed the 0  
to 50°C range).

**PROPORTIONAL BAND** -- This is the temperature range  
over which this output modulates

in the PWM mode or, in the  
digital mode, the deadband  
within which the output  
operates.

5

**DELAYED TILL ON --** This is the time after the previous  
output stage has gone to a state of 1  
before this stage goes to a state of  
1.

10

**LOGIC/PWM --** This is an internally stored state based  
on whether the output is an analog output  
or digital output.

15

**OFF VALUE --** This is the value/state that the output  
will assume if the ON/OFF point is off or  
the fire point is active.

20

**FIRE MODE/ILOCK --** This defines if AI/DI2 will operate  
as a fire mode input signal, and for  
AI/DI0 and AI/DI1 whether they will  
provide the interlock signals to the  
subsequent DO stages.

25

**FREE/ENGAGED --** This specifies if the digital output  
is to derive its output from the  
control module or to be uncommitted

and just follow any point control  
command from the UCI.

5      **FLOAT/MOD --**      This is relevant to DO\_1 only and defines  
whether in the analog output mode if  
outputs DO\_1 and DO\_2 are to be individual  
PWM output or if they are to act in  
conjunction as a floating output control.

10      **MAX VALUE --**      This defines the maximum that the  
associated outputs can assume during  
operation.

15      **MIN VALUE --**      This defines the minimum value that the  
associated outputs can assume during  
operation.

20      Also shown in FIGURE 3 with the output are modifiers  
that take effect in certain circumstances. Thus, for  
DO\_0, if the value of min air is non-zero, then this will  
provide an override as to when to turn on if the measured  
airflow is below this value. For all outputs, if the  
temperature sensor fails, a default FAIL SAFE value will  
be used by that output. For DO\_0, if the ON/OFF point is  
25      off all the FIRE state is on then and OFF value will be  
used by the output. For DO\_1 and DO\_2, and enabled

TABLE 1 shows parameters for the various modules of the present embodiment.

TABLE 1  
Internally Resident VAV Terminal Points

PARAMETER	DEFINITION
00DO	VAV ON/OFF
01AO/DO	Hardware output 0 (typically the auxiliary fan output)
02AO/DO	Hardware output 1 (typically the HEATER1 or float up output)
03AO/DO	Hardware output 2 (typically the HEATER2 or float down output)
04DO	Warm-up mode
05AO	Actuator desired position (0 to 100%)
07AO	LPS setpoint (from LPS setpoint module)
00AI	Setpoint from UCI
01AI/DI	Hardware input 0 (typically HEATER1 interlock)
02AI/DI	Hardware input 1 (typically HEATER2 interlock)
03AI/DI	Hardware input 2 (typically fire mode input)
04AI	Space temperature (from temperature sensor)
05AI	Damper position from feedback potentiometer
06AI	Airflow (liters per second from airflow sensor)
07DI	Fire mode (fire mode control from UCI)

FIGURE 4 illustrates the operation of liters per second module 400 that generates a liters per second setpoint based on the temperature setpoint at space



temperature. Liters per second (LPS) setpoint module 400  
uses the following parameters:

5           **PROPORTIONAL BAND** --       This is the temperature band  
  over which LPS setpoint module  
  400 is to scale.

10           **SETPOINT OFFSET** --    This is the temperature offset from  
  the VAV setpoint around which the  
  proportional band is to operate.

15           **FAIL SAFE VALUE** --    This is the LPS setpoint module 400  
  setpoint value that the VAV terminal  
  is to assume if the temperature  
  setpoint fails.

20           **MIN L/S** --            This is the minimum liters per second  
  setpoint value that LPS setpoint module  
  400 is to generate when the temperature is  
  at the low end of the proportional band.

25           **MAX L/S** --            This is the maximum liters per second  
  setpoint value that LPS module 400  
  generates when the temperature is at the  
  upper end of the proportional band.

5       **DIRECT/REVERSE** --     This flag defines whether the liters  
                              per seconds setpoint is to increase  
                              from MIN L/S to MAX L/S as the  
                              temperature increases or if the  
                              liters per second setpoint is to  
                              decrease from MAX L/S to MIN L/S as  
                              the temperature increases in a UCI  
                              point "warm-up" modifies the  
10                             DIRECT/REVERSE action of LPS setpoint  
                              module 400 to provide an early  
                              morning form of operation. The warm-  
                              up point derives its state only from  
                              the UCI.

15       **OFF VALUE** --     This is the liters per second setpoint  
                              value that LPS setpoint module 400 outputs  
                              when the VAV ON/OFF point is off.

20       **MIN AIR ON** --     This is the airflow value below which DO0  
                              will turn on. A value of 0 defines that  
                              this feature is inactive.

25       **MIN AIR OFF** --    This is the airflow value above which DO0  
                              will turn off.

      The LPS setpoint value that LPS setpoint module 400  
      generates is made available to the UCI and can be placed

into manual or output with lock control from the UCI.  
Thus, with particular reference to FIGURE 4, LPS setpoint  
module 400 receives ON/OFF input 256 from ON/OFF  
submodule 254, temperature sense (TS) fail input 238 from  
5 temperature conversion submodule 234, setpoint input 248  
from setpoint submodule 246, and process variable input  
240 from temperature conversion submodule 234. LPS  
setpoint module 400 also receives values for the  
proportional band as block 402 indicates, setpoint offset  
10 as block 404 indicates, FS value as block 406 indicates,  
a MIN L/S value as block 408 indicates, a MAX L/S value  
as block 410 indicates, a DIRECT/REVERSE flag value as  
block 412 indicates, an OFF VALUE flag as block 414  
indicates, a MIN AIR ON value as block 416 indicates, and  
15 a MIN AIR OFF value as block 418 indicates.

From DIRECT/REVERSE block 412 the DIRECT/REVERSE  
flag, as arrow 420 indicates, goes to COR submodule 422.  
COR submodule 422 also receives a warm-up signal from  
DIRECT/REVERSE warm-up submodule 424. DIRECT/REVERSE  
20 warm-up submodule 424 provides input to COR submodule 422  
in response to the value of the warm-up mode 04DO control  
signal 426. Thus, COR submodule 422 outputs to LPS value  
submodule 430. LPS value submodule 430 receives PV input  
240, setpoint input 248, and DIRECT/REVERSE flag value  
25 420 from COR submodule 422. LPS value submodule 430  
produces LPS output 432 according to instructions that  
perform the operations that plot 434 indicates. In plot

434, process variable 240 is treated as an independent variable that produces value for the LPS variable as a dependent variable. Plot 434 includes setpoint 248 and proportional band 402. As process variable 240 increases from a value at the origin of plot 434, depending upon whether DIRECT/REVERSE flag 420 is operating in the direct or reverse mode, the LPS value will change according to line 436 or 438, respectively. That is, if DIRECT/REVERSE flag 420 indicates that LPS value submodule 430 is to operate from in the direct mode, as PV 240 increases, the LPS value will change from a minimum LPS value 408 to a maximum LPS value 410. On the other hand, if DIRECT/REVERSE flag 420 indicates that LPS value submodule 430 is to operate in the reverse mode, then as PV 240 increases LPS value 432 will follow line 438 to range from MAX L/S value 410 to MIN L/S value 408. Operating in the direct mode, and in proportional band 402, as PV 240 increases, LPS value 432 will increase proportionally. On the other hand, if operating in the reverse mode according to line 438, as PV 240 increases, LPS value 432 will decrease proportionally.

Submodule 440 produces an output 442 to L/S setpoint submodule 444. Submodule 440 operates in the event that the temperature sensors fail parameter 238 indicates a failure in the temperature sensor. If the temperature sensor has failed then relay 440 will take the value of FS value 406 and send that to L/S setpoint submodule 444.

From L/S setpoint submodule 444, outputs go to LPS setpoint indicator 446 which is at the VAV terminal and as parameter value 448 for use in fuzzy logic control module 450 of FIGURE 5.

5           In FIGURE 4 also appears a block diagram of fuzzy logic control module 450 that drives the actuator for the damper in the VAV terminal. Based on the LPS set point 448 and a measured air flow determination from airflow sensor 18 (see FIGURE 1), fuzzy logic control module 450 provides an output signal to motor logic module 452. 10 With reference to fuzzy logic control module of FIGURE 5, the following parameters are defined:

15           N -- This is the conversion coefficient based on the duct size, air-flow factors, and air density to convert the sensed airflow pressure in Pascal to a liters per second value.

20           OFF VALUE -- This is the position that the actuator is to assume when the VAV ON/OFF point is off.

25           With these definitions, it can be understood that fuzzy logic control module 450 receives LPS set point 448 from LPS setpoint module 400 and ON/OFF input 256 from on/off submodule 254. In addition, fuzzy logic control module 450 receives a flow sensor parameter value 454 from air

flow pick-up probe 18, which pressure value submedial 456 converts to a pressure reading. From airflow pick-up probe 18, submodule 456 produces a pressure differential value. Within fuzzy logic control module 450, pressure  
5 submodule 458 produces an LPS sensed value to air flow submodule 460.

The LPS value that submodule 458 produces takes into consideration the property that the airflow is proportional to the square root of the differential  
10 pressure across air flow pick-up probe 18. The value of m is determined and is constant for a given VAV terminal. Airflow submodule 460 displays the actual LPS value as O6AI input value 462. In addition, the actual liters per measured operates as the process variable (PV) for fuzzy  
15 control submodule 464 of fuzzy logic module 450. Fuzzy control submodule 464 receives LPS setpoint 448 and, using a set of predetermined rules produces an output percentage value 466. Relay 468 sends output 470 from fuzzy logic control module 450 to motor logic submodule  
20 452 based on the status OFF flag 472. If the OFF flag equals 1, then from OFF VALUE program element 474, OFF VALUE 476 goes to interlock 468. Interlock 468, in this instance, sends OFF VALUE to motor logic submodule 452. If the OFF flag equals 0, then the output percentage  
25 value 466 passes through interlock 468 to motor logic submodule 452. Motor logic submodule 452 converts the output percentage from fuzzy logic control module 450 to

a control signal for motor 478 of the damper associated with the VAV terminal. That is, the output percentage 466 is the desired percentage opened for the damper of the VAV terminal.

5           Motor logic submodule 452 converts this percentage to either DRIVE UP signal 486 or DRIVE DOWN signal 488 based on the existing position of the damper in the VAV terminal. The Neuron® processor 452 absolutely calculates the position to which motor 478 moves the  
10           damper based on actual synchronous drive signals that motor 478 receives. See FIGURE 7, below, and accompanying description. In response to DRIVE UP signal 486 or DRIVE DOWN signal 488, motor 478 will move the position of the damper. Potentiometer 490 may also  
15           measure the position of the damper. Motor logic submodule 452 also sends a signal to compare submodule 492 of fuzzy logic control module 450, as does potentiometer 490.

20           Compare submodule 492 compares the motor logic submodule 452 value for the desired damper position to the actual damper position that the Neuron® processor calculates. In the event that there is a greater than 20% difference between the desired damper position and the actual damper position, compare submodule 492 sends a  
25           damper fail signal to damper fail submodule 494. Damper fail submodule 494 will indicate to VAV terminal controller 10 that a damper fail condition exists. To

further aid in the monitoring of the VAV terminal damper, output 470 from interlock 468 goes to motor desired submodule 496. Motor desired submodule 496 produces 05A0 output 498 that VAV terminal controller 10 may display.

5 To display the actual damper position, potentiometer 490 sends a measurement signal to motor actual submodule 500. Motor actual submodule 500 produces 05AI signal 502 to display the actual position of the VAV terminal damper.

10 The desired motor position signal that fuzzy logic control module 450 generates is a percentage (0 to 100%) value that goes to motor logic submodule 452. Motor logic submodule 452 then drives either the up or down motor on the damper actuator to desired damper position. Motor logic submodule 452 uses an internal algorithm that  
15 precisely and accurately counts the synchronous pulses of the up/down motor. As each pulse is directly related to the absolute position, motor logic submodule 452 may accurately position the damper actuator without the need for the feedback potentiometer (i.e., potentiometer 490).  
20 Feedback potentiometer 490 initially strokes the damper motor 478 the first time that VAV terminal controller 10 receives power. Thereafter it is used for informational purposes only (e.g., failure of the motor and/or its linkage). The position of the algorithm is unique in  
25 controlling these types of motors and includes techniques of storing the motor position during power outages.



5 Fuzzy logic control module 450, therefore, compares  
the LPS setpoint value 448 with the measured airflow 460  
and calculates a new desired position 470 for motor 478.  
This is done by determining the difference between the  
desired airflow and the actual airflow as well as the  
10 difference between the change and the airflow from the  
last sample kind. These values are then used to locate a  
point in a fuzzy logic real-based weight matrix and  
determine what influence they will have on the various  
output consequence degrees of membership. From this, a  
change in the desired motor position is acquired and  
added to the current desired position because motor logic  
submodule 452 to send the appropriate drive up 486 or  
drive down 488 signal to motor 478.

15 Fuzzy control submodule 464 may include a number of  
fuzzy logic algorithms for implementing the preferred  
embodiment. For example, those described in B. Kosko,  
Neural Networks and Fuzzy Systems: A Dynamical Systems  
Approach to Machine Intelligence, Englewood Cliffs, N.J.,  
20 Prentice Hall, 1992, and B. Kosko, Fuzzy Thinking: The  
New Science of Fuzzy Logic, New York, N.Y., Hyperion  
Press, describe various fuzzy logic algorithms that the  
present embodiment may employ. Based on these  
algorithms, coefficients may be defined and a weight  
25 matrix may be formed to provide the necessary weights  
upon which the fuzzy logic algorithm may operate. For  
purposes of the present invention, the above-cited

references are herein incorporated by reference. The weights and weight matrix that the preferred embodiment employs are shown respectively in FIGURES 5 and 6. The following discussion details more explicitly the operation of the preferred embodiment to perform the necessary fuzzy control steps.

In one embodiment of the present invention a hand-held console may be used that communicates with the VAV terminals over the LON in a basic format allows the user to set the VAV terminal unit address and calibrate the temperature sensor, the airflow sensor in pascals, and LPS actuator for the VAV terminal damper. The hand-held console permits setting the VAV unit address by allowing the user to select and enter the address of the VAV into the hand-held console. The user then pushes a service button on the VAV and the hand-held console establishes the VAV terminal address. Calibrating the temperature sensor is done by entering the real temperature into the hand-held console and selecting a calibrate function that the hand-held console provides. Calibrating the airflow sensor in pascals may be done in both the low end and the high end. The low end calibration of the Pascals value, below 50 Pascals, is entered directly into the hand-held console and the user selects the calibrate function. High end calibration is performed in a similar fashion, but requires value greater than 150 Pascals to be entered. Calibrating the airflow sensor in liters per

second is done by entering the true liters per second value and entering the calibrate command. The VAV back-calculates the appropriate Pascal value for the given flow and conversion coefficient and then uses this in its subsequent flow calculations. It should be noted that this is for small investments in calibration only. It cannot be used as a means of bypassing the conversion coefficient input. This is because large changes affect the granularity of the measured Pascal values. By selecting the actuator calibrate function, VAV terminal controller 10 will run the damper fully open for 130 seconds. Then, VAV terminal controller 10 will run the damper in the closed position until it no longer detects any damper movements. The VAV terminal controller 10 defines the fully opened position as 100% and the closed end stop at 0%.

FIGURES 7, 8, and 9 illustrate the circuitry and printed circuit board layout of the hardware that supports the above-described process for VAV terminal controller 10. In particular, FIGURES 7 and 8 illustrate circuit diagrams that represent the various logical circuit components that form the present embodiment. Although the circuitry of FIGURES of 7 and 8 is apparent on inspection of FIGURES 7 and 8, certain aspects of the associated circuitry warrant specific mention.

For example, within dashed line 510 of the circuitry in FIGURE 7 appears a subcircuit including resistor 512,

diode 514, transistor 516, and resistor 518. Subcircuit 510 performs the function of tracking the position of the damper by generating a signal that the Neuron® in U8 processor 520 of FIGURE 8 can use to count the number of alternating current cycles as they occur in the main 24-volt power supply to VAV terminal controller 10. In the present embodiment, motor 478 is a synchronous motor, and so its operation is synchronous to the alternating current existing across its main windings. The present embodiment, for example, equates six cycles of alternating current to one revolution of motor 478. Because of the synchronous nature of motor 478, it is possible to keep track of the number of turns that motor 478 takes by simply counting the number of alternating current cycles that it receives.

In the present embodiment, it may be further determined that taking the damper from fully closed to fully opened requires a certain number of revolutions of motor 478. By determining the number of motor 478 revolutions necessary to take the damper from a fully closed to a fully opened position, it is possible to determine the time necessary to open the damper to intermediate positions between fully opened and fully closed. For example, if the damper requires 90 seconds to go from fully closed to fully opened with 50 cycle alternating current, it can be determined that the requirement for 4500 cycles of alternating current (or

750 revolutions of motor 478) are necessary to take the damper from the fully closed to the fully opened position. Since this relationship is linear, to open the damper from a fully closed position would require one-half this number, or 2250 voltage cycles to motor 478. It is possible, therefore, with the present embodiment to precisely control the position of the damper by precisely controlling and accounting for the amount of time that alternating current voltage is delivered to motor 478.

FIGURE 8 also shows subcircuit 522 that includes Hall Effect switch 524. Present embodiment, using subcircuit 522 permits setting and identify particular VAV terminal controllers using the combination of a magnet with Hall Effect switch 524. By placing a magnet near Hall Effect switch 524, it is possible to identify the specific VAV terminal controller 10 and provide this as an input to a hand-held controller for controlling the set points and other characteristics of that VAV terminal controller 10.

Hall Effect switch 524, at a minimal cost permits non-intrusive identification of a VAV terminal controller 10 in a VAV air conditioning system. Previous devices required insertion of pins or other external circuitry for the identification and control of a particular VAV terminal controller 10 in the VAV air conditioning system. By using, instead, the combination of the magnet and the Hall Effect switch 524, no physical intrusion

incurs that may undesirably affect the electrical characteristics of the circuits that appear in FIGURES 7 and 8 for VAV terminal controller 10.

FIGURE 9 shows a top overlay diagram for printed circuit board 530 that includes the hardware for VAV terminal controller 10. Each of the identification alphanumerics in top overlay diagram 530 corresponds to the identified circuits and components that appear in FIGURES 7 and 8 of the present embodiment. A particularly important feature of the present invention is the ability to accommodate all of the various components of the present embodiment on a single printed circuit board. This permits the advantageous feature of local placement of VAV terminal controller 10 with the VAV actuator.

A particularly interesting feature of the component layout that appears in top overlay diagram 530 is the dual use of a heat sink associated with the circuit. That is, in top overlay 530 appear regulators 532 and 534. Regulators 532 and 534 are adjacent to flow sensor 536 and produce heat that may affect other components of VAV terminal controller 10. To overcome this potential problem, an aluminum or other metal heat sink may be placed around regulators 532 and 534. In the present embodiment, the same heat sink may be further expanded around flow sensor 536. Placing the heat sink near flow sensor 536 minimizes temperature variations that may

affect the operation of flow sensor 536. That is, as external temperature changes in the environment around VAV terminal controller 10, the same heat sink that operates in conjunction with regulators 532 and 534 prevents severe fluctuations in the temperature around flow sensor 536. This produces increased stability in the operation of VAV terminal controller 10.

#### ALTERNATIVE EMBODIMENTS

There are any number of alternatives or changes in the design of the VAV terminal controller of the present invention which may be readily apparent to one ordinary skill in the art. Such alternatives may not be employed in the systems of the above-illustrated embodiments for any number of reasons, such as cost and performance considerations, size constraints, availability of materials, arbitrary design decision, and the like. A number of these alternatives have been mentioned and described above. There are even further alternatives to forming embodiments of present invention. Such configurations and embodiments are well within the scope of the present invention. Thus, the invention is intended to be limited by the claims which are meant to cover such obvious alternatives and deviations from the above-illustrated and preferred designs.

WHAT IS CLAIMED IS:

1. A controller for a variable air volume terminal, of a variable air volume air conditioning system, comprising:

5 temperature sensing circuitry for generating a temperature process value;

setpoint determining circuitry for establishing a temperature setpoint;

10 airflow signal circuitry for generating an airflow setpoint in response to said temperature process value and said temperature setpoint;

flow sensing circuitry for generating a flow process value in response to a predetermined set of flow sensing inputs; and

15 damper control circuitry for generating a damper motor operation signal to control the damper motor in response to said flow process value and said airflow setpoint, said damper control circuitry comprising a fuzzy logic control mechanism for implementing a set of  
20 fuzzy logic rule-based instructions in generating said damper motor operating signal.

2. The controller of Claim 1, wherein said  
25 temperature sensing circuitry, said setpoint determining circuitry, said airflow signal circuitry, said flow sensing circuitry, and said damper control circuitry are formed sufficiently small for placement on a single



printed circuit board, said printed circuit board formed for placement on the damper motor when said damper motor is installed in the damper shaft.

5           3.    The controller of Claim 1, wherein said  
temperature sensing circuitry, said setpoint determining  
circuitry, said airflow signal circuitry, and said flow  
sensing circuitry operate under an open protocol that  
10       permits system-wide control and monitoring of said  
controller within said variable air volume air  
conditioning system.

15           4.    The controller of Claim 1, wherein said  
temperature sensing circuitry, said setpoint determining  
circuitry, said airflow signal circuitry, and said flow  
sensing circuitry are associated to permit pressure  
dependent operation of said controller.

20           5.    The controller of Claim 1, wherein said  
temperature sensing circuitry, said setpoint determining  
circuitry, said airflow signal circuitry, and said flow  
sensing circuitry are associated to permit pressure  
independent operation of said controller.

25           6.    The controller of Claim 1, wherein said  
controller further comprises circuitry for permitting a

fire mode of operation for said variable air volume terminal.

5        7.    The controller of Claim 1, further comprising  
circuitry for permitting a warm-up mode of operation for  
said variable air volume terminal.

10       8.    The controller of Claim 1, further comprising  
circuitry for permitting remote control of said  
controller for controlling operation of said variable air  
volume terminal.

15       9.    The controller of Claim 1, wherein said damper  
control circuitry further comprises circuitry for  
automatically calibrating the damper stroke of the damper  
in the variable air volume terminal.

20       10.   The controller of Claim 1, wherein said damper  
control circuitry further comprises circuitry for  
manually driving the damper of the variable air volume  
terminal.

25       11.   The controller of Claim 1, wherein said damper  
control circuitry further comprises circuitry for  
automatically stopping movement of the damper at a  
control stop position for the damper.

12. The controller of Claim 1, further comprising  
Hall Effect circuitry for identifying and controlling  
operation of said temperature sensing circuitry, said  
setpoint determining circuitry, said airflow signal  
5 circuitry, said flow sensing circuitry, and said damper  
control circuitry upon placing a predetermined magnet  
device proximate said Hall Effect circuitry.

13. The controller of Claim 1, wherein said damper  
10 control circuitry further comprises circuitry for  
counting alternating current voltage frequencies to said  
controller and determining from said alternating current  
voltage cycles the position of the damper in response to  
operation of said damper motor.

14. The controller of Claim 1, further comprising a  
15 shield surrounding said flow sensing circuitry for  
limiting affects of temperature variations on operation  
of said flow sensing circuitry.

15. A method for controlling a variable air volume terminal, having a damper and a damper motor, comprising the steps of:

generating a temperature process value using  
5 temperature sensing circuitry;

establishing a temperature setpoint using setpoint determining circuitry;

generating an airflow setpoint in response to said temperature process value and said temperature setpoint  
10 using airflow signal circuitry;

generating a flow process value in response to a predetermined set of flow sensing inputs using flow sensing circuitry; and

generating a damper motor operation signal using  
15 damper control circuitry to control the damper motor in response to said flow process value and said airflow setpoint, said damper motor operation signal generating step further comprising the step of implementing a set of fuzzy logic rule-based instructions in generating said  
20 damper motor operating signal.

16. The method of Claim 5, further comprising the step of forming said temperature sensing circuitry, said set point determining circuitry, said air flow signal  
25 circuitry, said flow sensing circuitry, and said damper control circuitry sufficiently small for their placement on a single printed circuit board, said printed circuit

board formed sufficiently small for placement on the damper motor when said damper motor is installed in the damper shaft.

5           17. The method of Claim 15, further comprising the  
step of operating said temperature sensing circuitry,  
said set point determining circuitry, said air flow  
signal circuitry, and said flow sensing circuitry under  
10 an open protocol that permits system-wide control and  
monitoring of said controller within said variable air  
volume air conditioning system.

15           18. The method of Claim 15, further comprising the  
step of associating said temperature sensing circuitry,  
said set point determining circuitry, said air flow  
signal circuitry, and said flow sensing circuitry to  
permit pressure dependent operation of said controller.

20           19. The method of Claim 15, further comprising the  
step of associating said temperature sensing circuitry,  
said set point determining circuitry, said air flow  
signal circuitry, and said flow sensing circuitry to  
permit pressure independent operation of said controller.

25           20. The method of Claim 15, further comprising the  
step of permitting a fire mode of operation for said  
variable air volume terminal.

21. The method of Claim 15, further comprising the step of operating said variable air volume terminal in a warm-up mode of operation.

5           22. The method of Claim 15, further comprising circuitry for permitting remote control of said controller for controlling operation of said variable air volume terminal.

10           23. The method of Claim 15, further comprising the step of automatically calibrating the damper stroke of the damper in the variable air volume terminal.

15           24. The method of Claim 15, further comprising the step of manually driving the damper of the variable air volume terminal.

20           25. The method of Claim 15, further comprising the step of automatically stopping movement of the damper at a control stop for the damper.

25           26. The method of Claim 15, further comprising the step of identifying and controlling operation of said temperature sensing circuitry, said setpoint determining circuitry, said airflow signal circuitry, said flow sensing circuitry, and said damper control circuitry by

placing a predetermined magnet device proximate a Hall Effect circuit of the controller.

5           27. The method of Claim 15, further comprising the step of counting alternating current voltage frequencies to the controller and determining from the alternating current voltage cycles the position of the damper in response to operation of the damper motor.

10           28. The method of Claim 15, further comprising the step of limiting affects of temperature variations on operation of said flow sensing circuitry using an enclosed shield surrounding the airflow signal circuitry.

29. A variable air volume air conditioning system,  
comprising:

a controller for a variable air volume terminal;

a variable air volume terminal comprising a damper,  
5 a damper motor associated to move said damper, and a  
terminal controller for controlling operation of said  
damper motor, said terminal controller comprising:

temperature sensing circuitry for generating a  
temperature process value;

10 setpoint determining circuitry for establishing  
a temperature setpoint;

airflow signal circuitry for generating an  
airflow setpoint in response to said temperature  
process value and said temperature setpoint;

15 flow sensing circuitry for generating a flow  
process value in response to a predetermined set of  
flow sensing inputs; and

damper control circuitry for generating a  
damper motor operation signal to control the damper  
20 motor in response to said flow process value and  
said airflow setpoint, said damper control circuitry  
comprising a fuzzy logic control mechanism for  
implementing a set of fuzzy logic rule-based  
instructions in generating said damper motor  
25 operating signal.



30. The system of Claim 29, wherein said temperature sensing circuitry, said setpoint determining circuitry, said airflow signal circuitry, said flow sensing circuitry, and said damper control circuitry are formed sufficiently small for placement on a single printed circuit board, said printed circuit board being formed for placement on the damper motor when said damper motor is installed in the damper shaft.

31. The system of Claim 29, wherein said temperature sensing circuitry, said setpoint determining circuitry, said airflow signal circuitry, and said flow sensing circuitry operate under an open protocol that permits system-wide control and monitoring of said controller within said variable air volume air conditioning system.

32. The system of Claim 29, wherein said temperature sensing circuitry, said setpoint determining circuitry, said airflow signal circuitry, and said flow sensing circuitry are associated to permit pressure dependent operation of said controller.

33. The system of Claim 29, wherein said temperature sensing circuitry, said set point determining circuitry, said air flow signal circuitry, and said flow

sensing circuitry, are associated to permit pressure independent operation of said controller.

5 34. The system of Claim 29, wherein said controller further comprises circuitry for permitting a fire mode of operation for said variable air volume terminal.

10 35. The system of Claim 29, further comprising circuitry for permitting a warm-up mode of operation for said variable air volume terminal.

15 36. The system of Claim 29, further comprising circuitry for permitting remote control of said controller for controlling operation of said variable air volume terminal.

20 37. The system of Claim 29, wherein said damper control circuitry further comprises circuitry for automatically calibrating the damper stroke of the damper in the variable air volume terminal.

25 38. The system of Claim 29, wherein said damper control circuitry further comprises circuitry for manually driving the damper of the variable air volume terminal.

39. The system of Claim 29, wherein said damper control circuitry further comprises circuitry for automatically stopping movement of the damper at a control stop position for the damper.

5

40. The system of Claim 29, further comprising Hall Effect circuitry for identifying and controlling operation of said temperature sensing circuitry, said setpoint determining circuitry, said airflow signal circuitry, said flow sensing circuitry, and said damper control circuitry upon placing a predetermined magnet device in proximity to said Hall Effect circuitry.

10

41. The system of Claim 29, wherein said damper control circuitry further comprises circuitry for counting alternating current voltage frequencies to said controller and determining from said alternating current voltage cycles the position of the damper in response to operation of said damper motor.

15

20

42. The system of Claim 29, further comprising a shield surrounding said flow sensing circuitry for limiting affects of temperature variations on operation of said flow sensing circuitry.

43. A controller for an environmental control system, comprising:

temperature circuitry for receiving a signal representing a temperature process value;

5 setpoint circuitry for receiving a signal representing a temperature setpoint;

demand signal generating circuitry for generating a demand signal in response to said temperature process value and said temperature setpoint;

10 flow sensing circuitry for generating a flow process value in response to a predetermined set of flow sensing inputs; and

flow medium control signal generating circuitry for generating a flow medium control signal to control an actuator in response to said flow process value and said demand signal, said flow medium control signal generating circuitry comprising a fuzzy logic control mechanism for implementing a set of fuzzy logic rule-based instructions in generating said flow medium control signal.

20

44. The controller of Claim 43 wherein the flow medium control signal generating circuitry is operable to generate a flow medium control signal to an actuator, such that the flow medium control signal represents an offset, and wherein said offset represents an incremental move of the actuator.

25

5      45. The controller of Claim 43 wherein the flow medium control signal generating curcuitry is operable to generate a flow medium control signal to an actuator, such that the flow medium control signal represents instructions to the actuator to move the actuator from a first position to a second position.

46. A method for controlling an environment,  
comprising the steps of:

receiving a signal representing a temperature  
process value;

5 receiving a signal representing a temperature  
setpoint;

generating a demand signal in response to said  
temperature process value and said temperature setpoint;

10 generating a flow process value in response to a  
predetermined set of flow sensing inputs; and

generating a flow medium control signal to control  
an actuator in response to said flow process value and  
said demand signal, said flow medium control signal  
generating step further comprising the step implementing  
15 a set of fuzzy logic rule-based instructions in  
generating said flow medium control signal.

47. The method of Claim 46 wherein the flow medium  
control signal generating step comprises generating a  
20 flow medium control signal to an actuator, such that the  
flow medium control signal represents an offset, and  
wherein said offset represents an incremental move of the  
actuator.

25 48. The method of Claim 46 wherein the flow medium  
control signal generating step comprises generating a  
flow medium control signal to an actuator, such that the

# Lebenslauf

[REDACTED]

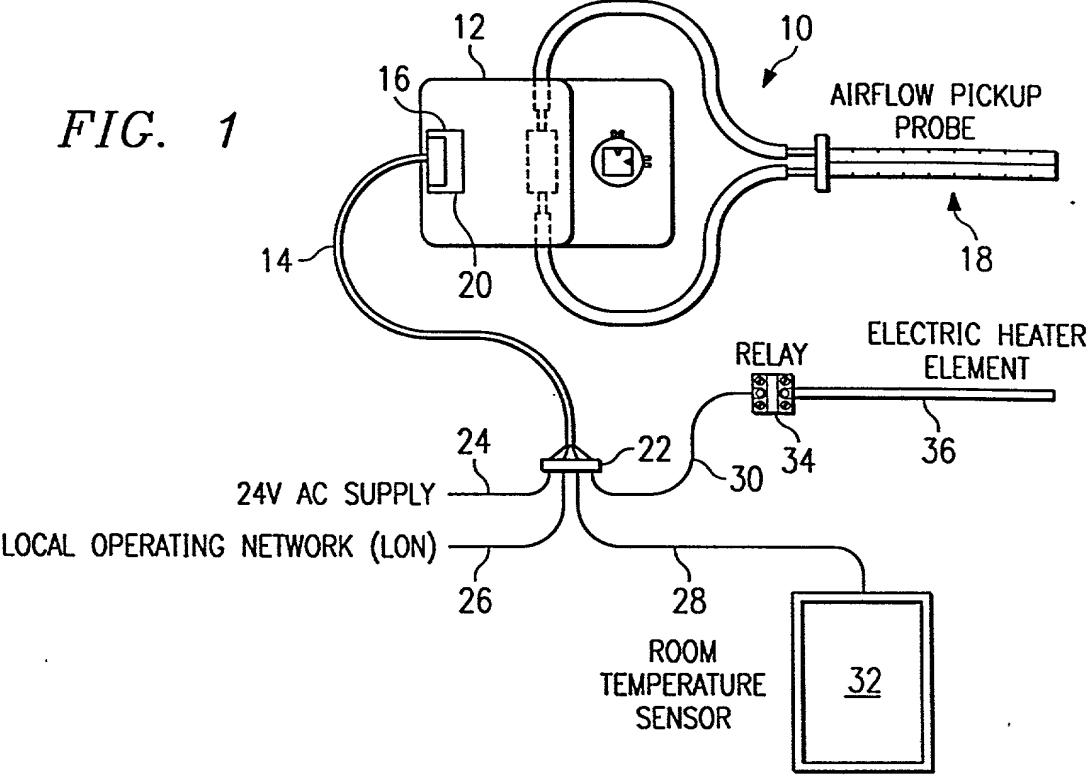
flow medium control signal represents instructions to the actuator to move the actuator from a first position to a second position.

VARIABLE AIR VOLUME ENVIRONMENTAL MANAGEMENT  
SYSTEM INCLUDING A FUZZY LOGIC CONTROL SYSTEM

ABSTRACT OF THE DISCLOSURE

5 A controller for a variable air volume terminal of a  
variable air volume air conditioning system which  
comprises a temperature sensing circuitry for generating  
a temperature process value, a setpoint determining  
circuitry for establishing a temperature setpoint, an  
airflow signal circuitry for generating an airflow  
setpoint in response to the temperature process value and  
the temperature setpoint. A flow sensing circuitry for  
10 generating a flow process value in response to a  
predetermined set of flow sensing inputs and damper  
control circuitry for generating a damper motor operation  
signal to control the damper motor in response to the  
flow process value and the airflow setpoint. The damper  
15 control circuitry comprises a fuzzy logic control  
mechanism for implementing a set of fuzzy logic rule-  
based instructions in generating the damper motor  
operating signal.



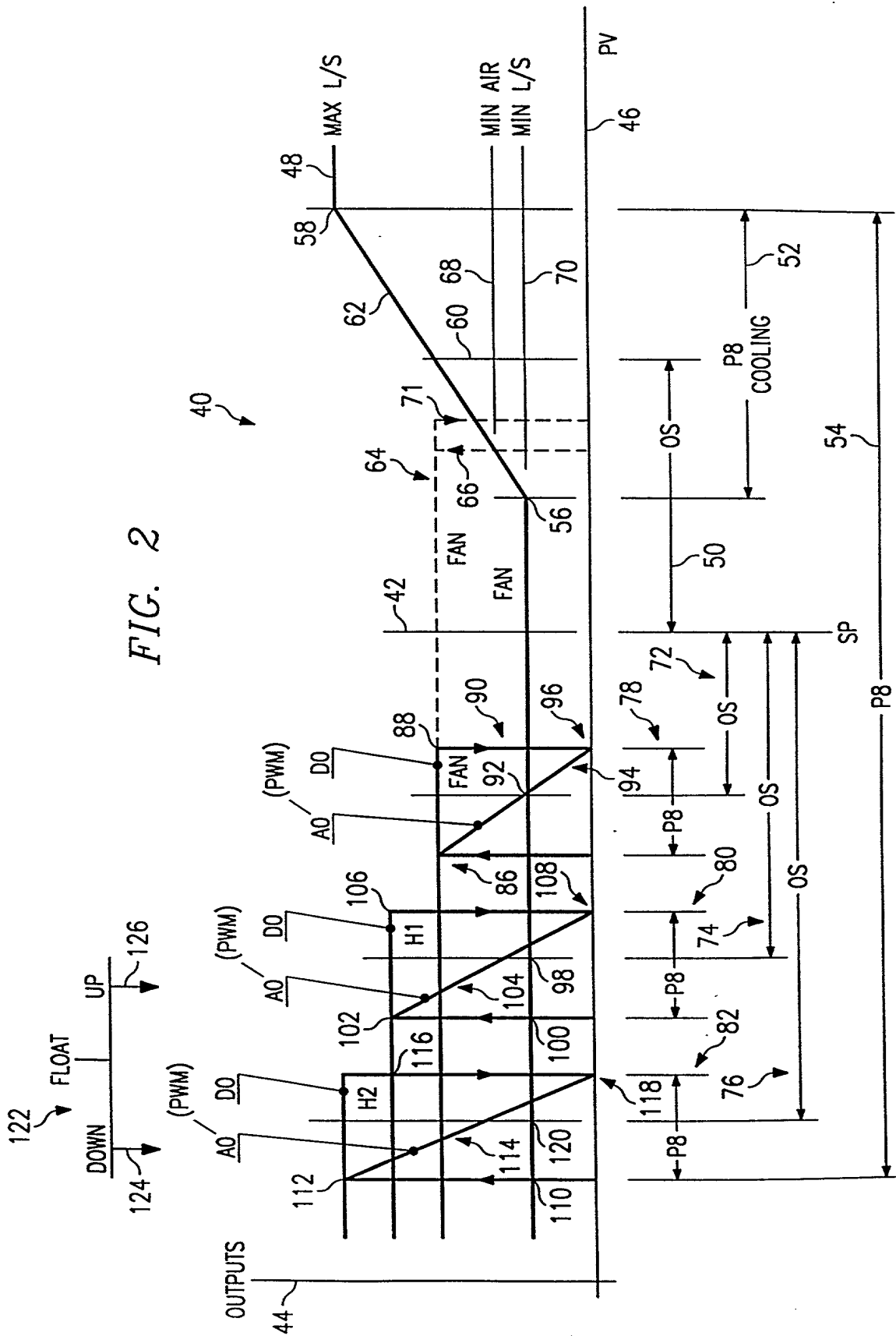


← FLOW ERROR

X

		-100	-40	-10	0	+10	+40	+100
		NB	NH	NS	ZE	PS	PM	PB
FLOW ERROR	↑	-100	NB	PB	PB	PB	PM	PS
	Y	-40	NH	PM	PM	PM	PS	PS
		-10	NS	PS	PS	PS	PS	PS
		0	ZE	PS	PS	ZE	NS	NS
		+10	PS	NS	NS	NS	NS	NS
		+40	PM	NS	NM	NM	NM	NM
	↓	+100	PB	NS	NB	NB	NB	NB

**FIG. 6**





[illegible]

	X	Y	Z		X	Y	Z
PB	-100	-100	50	NB	100	100	50
	-40	-100			40	100	
	-10	100			10	100	
	0	-100			0	100	
	10	-100			-10	100	
PM	-100	-40	25	NM	-40	100	25
	-40	-40			-10	40	
	-10	-40			0	40	
	0	-40			10	40	
	10	-40			40	40	
	40	-100			100	40	
PS	-100	-10	10	NS	40	0	10
	-40	-10			100	0	
	-10	-10			-100	10	
	0	-10			-40	10	
	10	-10			-10	10	
	40	-10			0	10	
	100	-10			10	10	
	-100	0			40	10	
	-40	0			100	10	
	40	-40			-100	40	
	100	-40			-40	40	
	100	-100			-100	100	
ZE	-10	0	7				
	0	0	7				
	10	0	7				

FIG. 5

FIG. 7A

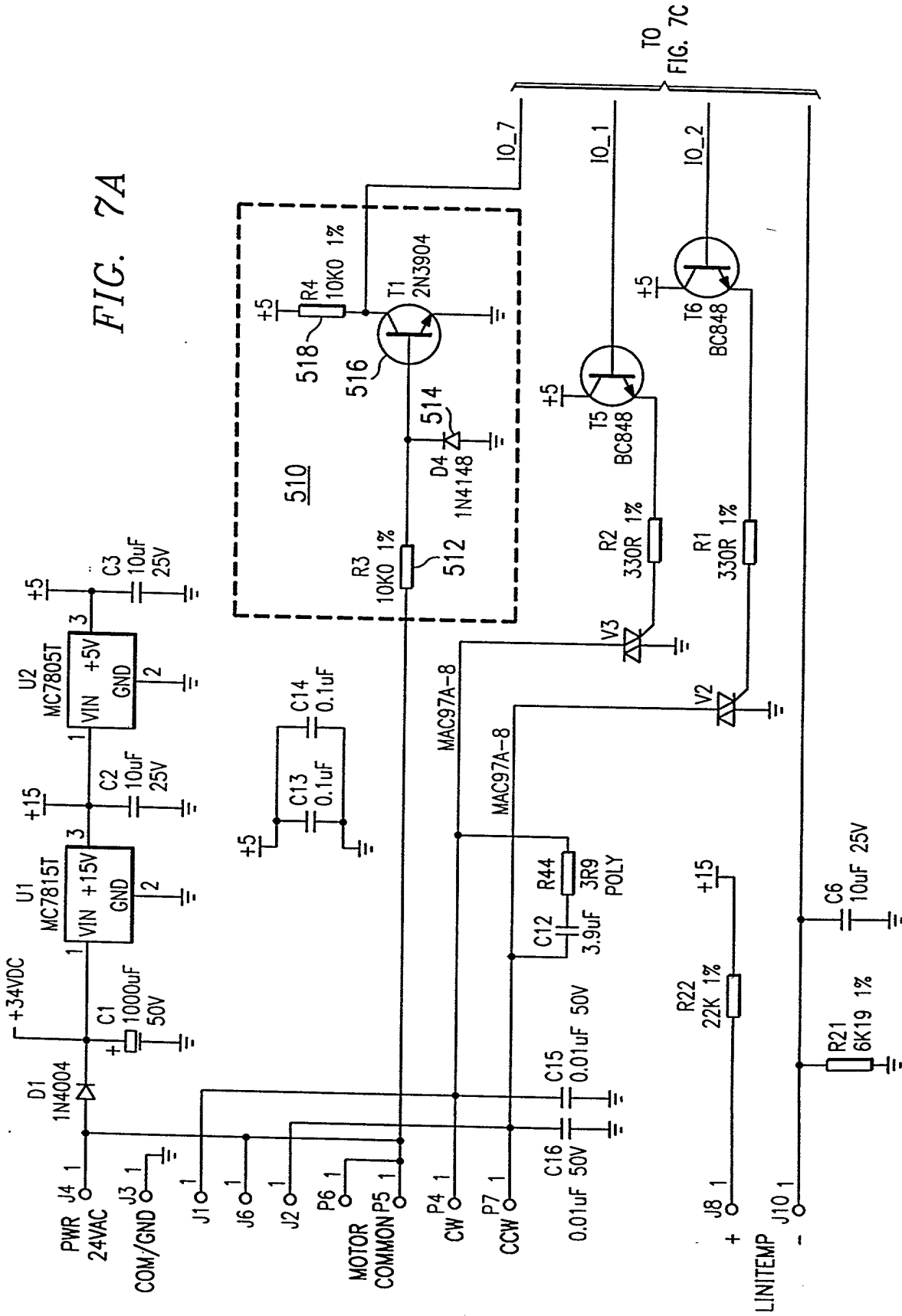
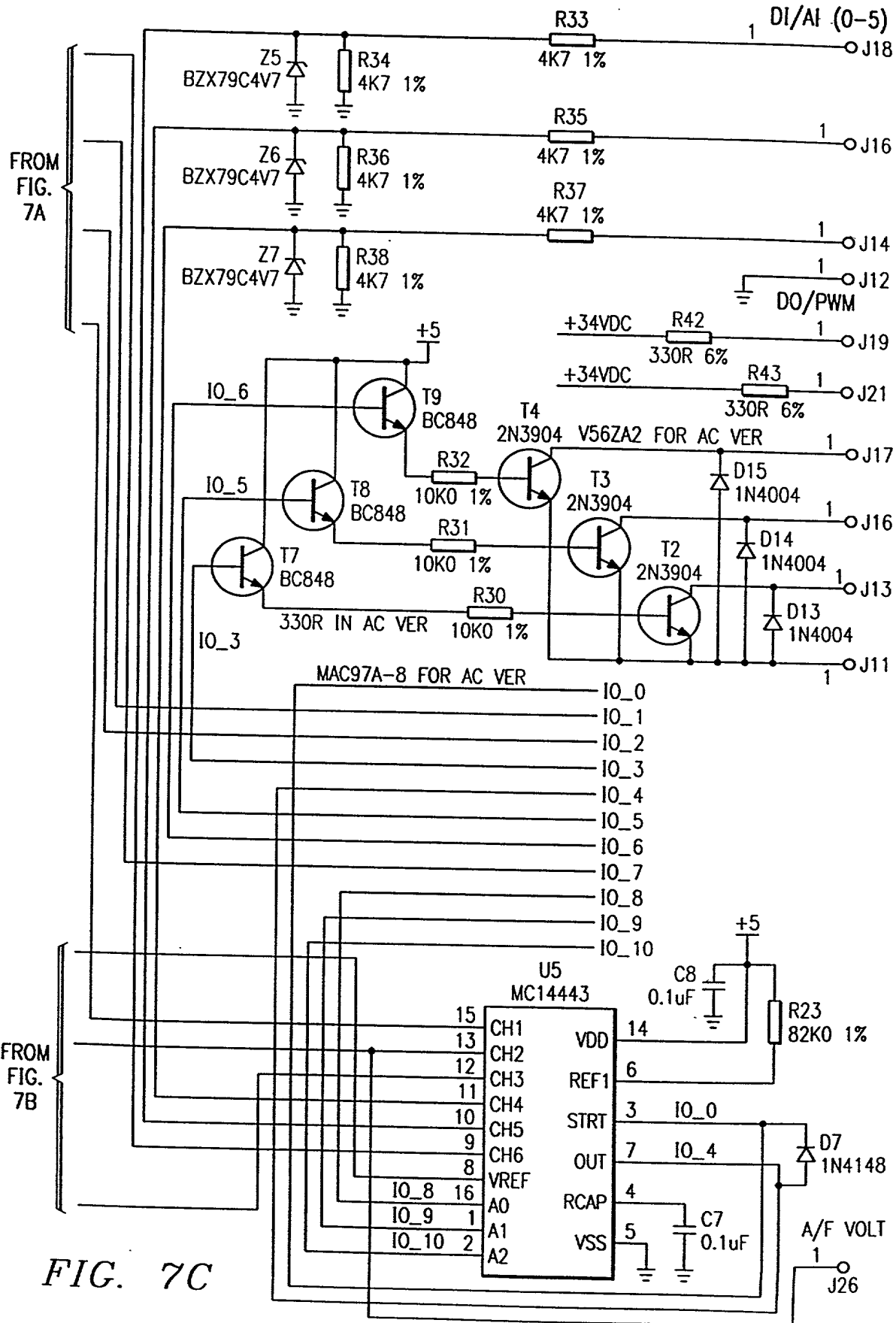


FIG. 7C

FIG. 7B

FIG. 7B

TO  
FIG. 7C





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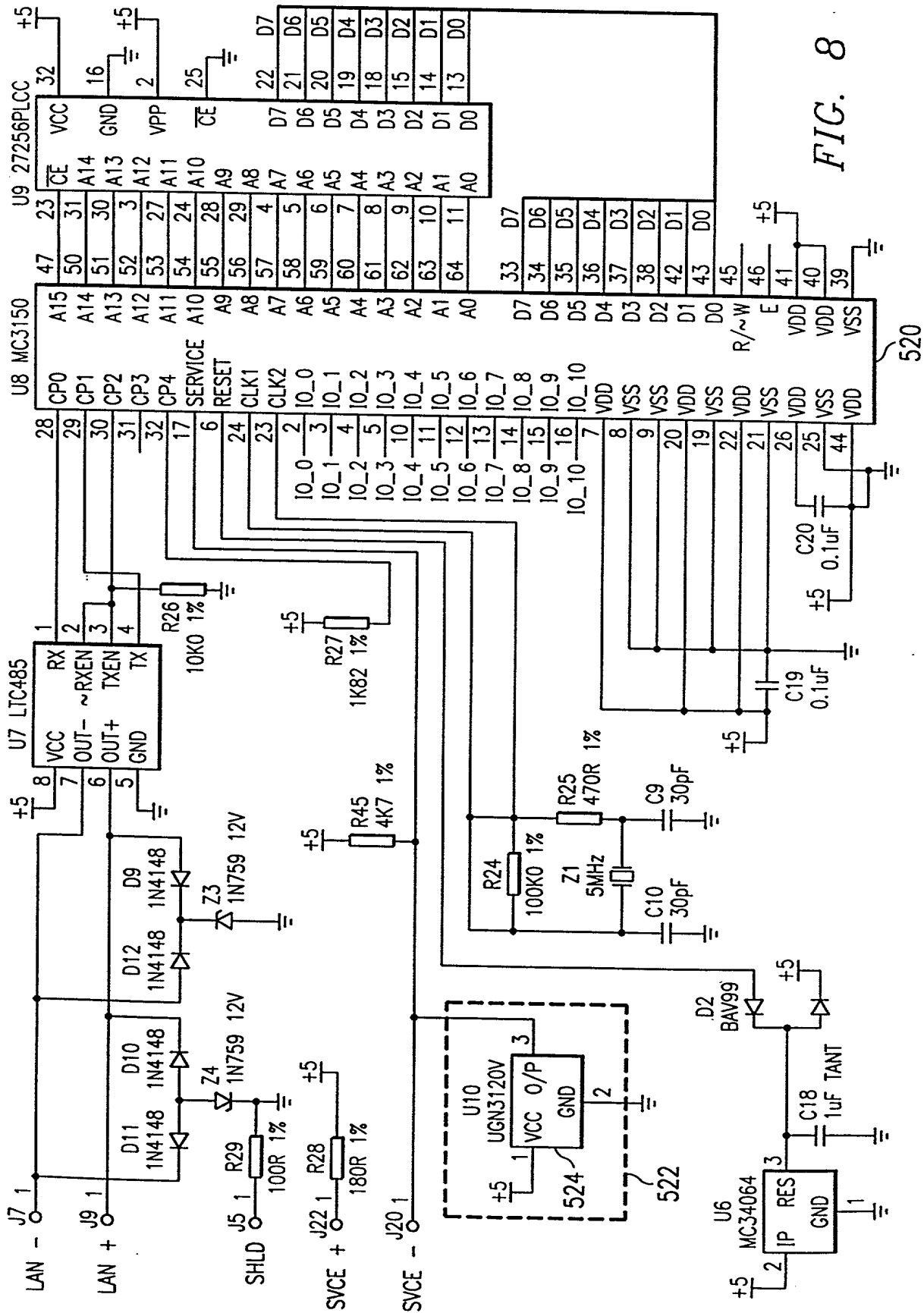
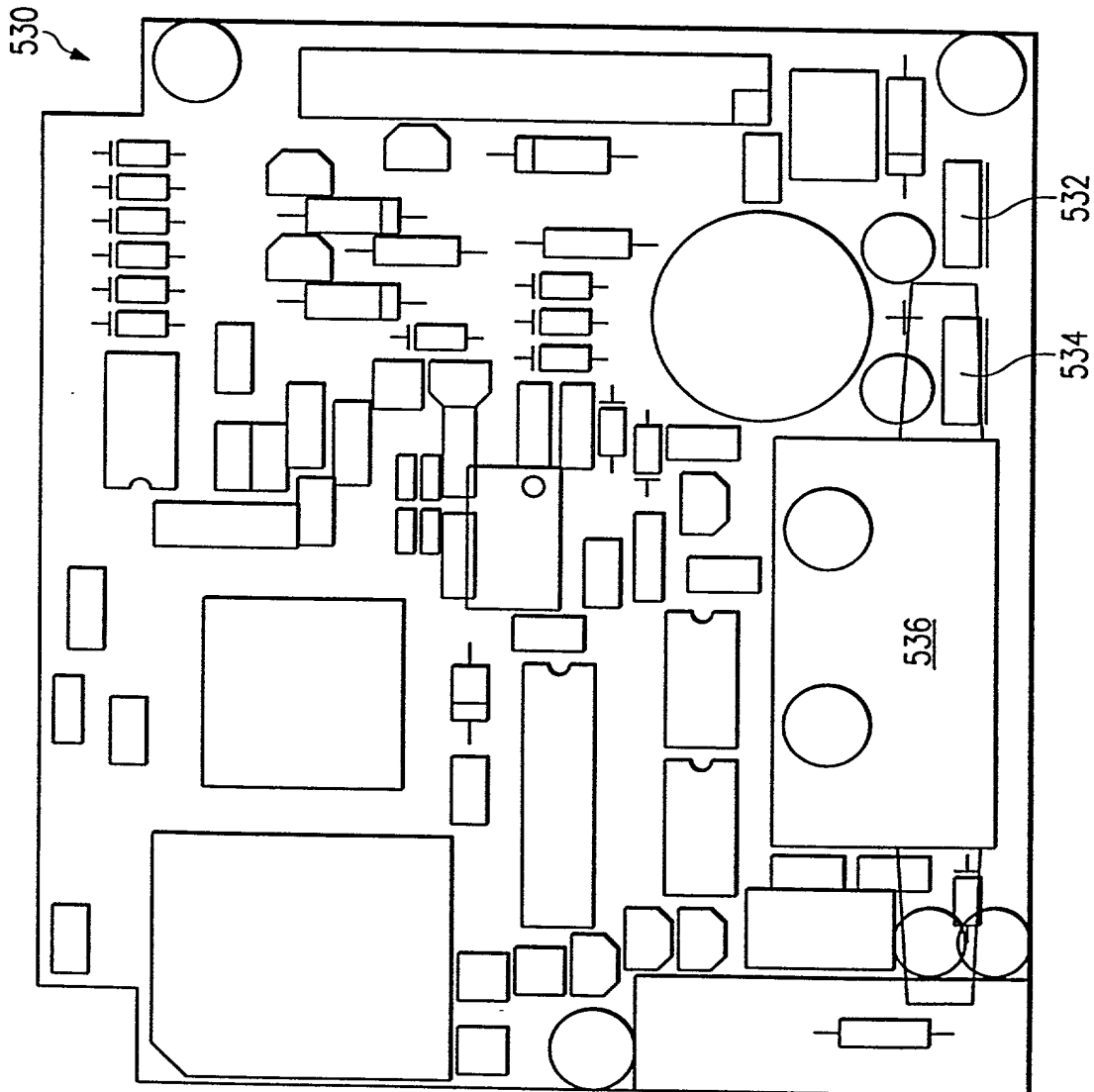


FIG. 8

FIG. 9



IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Reissue Applicant: EMS Control Systems International  
Original Inventors: Scholten, et al.  
Original Patent No.: 5,450,999  
Issue Date: September 19, 1995  
Title: VARIABLE SYSTEM INCLUDING  
ENVIRONMENTAL MANAGEMENT SYSTEM  
INCLUDING A FUZZY LOGIC SYSTEM

Honorable Commissioner of  
Patents and Trademarks  
Washington, D.C. 20231

Dear Sir:

REISSUE DECLARATION BY INVENTORS AND POWER OF ATTORNEY

We, the undersigned, declare and state as follows:

1. Jean Henry Albert Scholten is an Australian citizen residing at 4116 Williams Court, Tarrant County, Grapevine Texas, 76151.

2. Anno Johannes Scholten is an Australian citizen residing at 2428 Brittany Lane, Grapevine, Tarrant County, Texas 76051.

3. We believe we are the original, first and joint inventors of the subject matter that is claimed and for which a reissue patent is sought on the invention entitled Variable Air Volume Environmental Management System Including a Fuzzy

Logic Control System, the specification of which is attached hereto.

4. We have reviewed and understand the contents of the subject specification, including the claims and amendments made thereto as referred to hereinbelow and submitted herewith.

5. We acknowledge the duty to disclose information that is material to the examination of this application in accordance with 37 C.F.R. § 1.56.

6. On information and belief, United States Patent No. 5,450,999 (the "999" Patent) from which a reissue patent is sought herein, is partly inoperative or invalid because of certain errors made without any deceptive intent, due to inadvertence and mistake, by virtue of the patent claiming less than we had a right to claim in the patent.

7. On information and belief, the present reissue application seeks to enlarge the scope of the claims of the "999" Patent.

8. We did not fully appreciate the true scope of the invention disclosed in the patent until after allowance of the patent. This error occurred due to assumptions that we made regarding the extent and scope of the prior art compared to our invention.

9. In the original application, the claims included a limitation directed towards a damper which controls the volume

of air passing from an air terminal. The damper adjusts air flow according to instructions received from a fuzzy logic control mechanism. The fuzzy logic control mechanism determines incremental damper positions by comparing a sensed temperature measurement with a temperature setpoint to determine an airflow setpoint, and by adjusting the damper position based upon a comparison of the airflow setpoint and a sensed airflow measurement.

10. The damper is not required to define a variable air volume control system that is patentable over the prior art to the "999" Patent. During prosecution of the "999" Patent, we mistakenly believed that a damper was necessary to define the invention over the prior art. We were mistaken in our belief because, prior to our invention, it was not known to use a fuzzy logic control mechanism to control an environment associated with an air terminal. The damper limitation in the claims of the "999" Patent therefore was not necessary to define patentable subject matter. This misunderstanding on the patentability of the subject matter in Applicant's specification arose without any deceptive intent on our part because we failed to appreciate that the claims did not embrace the full scope of our invention.

11. Claim language regarding using the present invention to control an environment by varying the amount of air through an air terminal is not required to patent the current invention over the prior art of the "999" Patent. The current invention applies to controlling an environment by varying the flow of media other than air, as well as varying the flow of air. For example, at Col. 7 lines 59-66 and Col. 8 lines 1-4

the "999" Patent discusses one embodiment of the current invention whereby the invention controls the flow of water through coils. This misunderstanding on the patentability of the subject matter in Applicant's specification arose without any deceptive intent on our part because we failed to appreciate that the claims did not embrace the full scope of our invention.

12. New claims 43-48 include independent Claims 43 and 46. Independent Claim 43 recites a controller for an environmental control system. Independent Claim 46 recites a method for controlling an environment. These independent claims broaden the protection of the "999" Patent by eliminating the damper limitation, adding language regarding controlling an actuator, and eliminating the claim language regarding the use of the invention to control air flow through a terminal. Dependent Claims 44-45 and 47-48 regard using the present invention to move an actuator by sending an offset signal to the actuator or by moving the actuator to a defined new position. Support for precise control by the present invention is found in the discussion of an embodiment at Col. 17, lines 18-38. Furthermore, Claims 44-45 and 47-48 depend from the independent claims and are thus allowable as further describing the inventive concept.

We hereby appoint

Jerry W. Mills	Reg. No. 23,005
Robert M. Chiaviello, Jr.	Reg. No. 32,461
Ann C. Livingston	Reg. No. 32,479
William N. Hulsey III	Reg. No. 33,402
Thomas R. Felger	Reg. No. 28,842
Charles S. Fish	Reg. No. 35,870
Robert H. Johnston III	Reg. No. 37,364
Wei Wei Jeang	Reg. No. 33,305

Kevin J. Meek	Reg. No. 33,738
Anthony E. Peterman	Reg. No. 38,270
Barton E. Showalter	Reg. No. 38,302
David G. Wille	Reg. No. 38,363
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Daniel P. Stewart	Reg. No. 41,332
Roger J. Fulghum	Reg. No. 39,678
Rodger L. Tate	Reg. No. 27,399
Scott F. Partridge	Reg. No. 28,142
James B. Arpin	Reg. No. 33,470
James Remenick	Reg. No. 36,902
Jay B. Johnson	Reg. No. 38,193
Christopher C. Campbell	Reg. No. 37,291
Stacy B. Margolies	Reg. No. 39,760
Robert W. Holland	Reg. No. 40,020
Steven R. Sprinkle	Reg. No. 40,825

all of the firm of Baker & Botts, L.L.P., as my attorneys with full power of substitution and revocation, to prosecute this application and to transact all business in the United States Patent and Trademark Office connected therewith, and to file and prosecute any international patent applications filed thereon before any international authorities.

12. I hereby declare that all statements made herein of our own knowledge are true and that all statements made on information and belief to be true; and further that these statements were made with knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001, Title 18 of the

United States Code and that willful false statements may jeopardize the validity of the application or any patent issuing thereon.

By: 

Jean Henry Albert Scholten

Dated: 17SEP97By: 

Anno Johannes Scholten

Dated: 18SEP'97

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PATENT  
Attorney Docket No.: CSI-1260

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In the Application of: Jean Henry Albert Scholten, et al.  
Serial No. 08/932,652  
Filing Date: September 18, 1997  
Group Art No. 3744  
Title VARIABLE AIR VOLUME ENVIRONMENTAL  
MANAGEMENT SYSTEM INCLUDING A FUZZY  
LOGIC CONTROL SYSTEM

Assistant Commissioner of Patents  
Washington, D.C. 20231

CERTIFICATION UNDER 37 CFR §1.8

I hereby certify that this document is being  
deposited in the United States Postal Service as  
first class mail on the date identified below in an  
envelope addressed to: Assistant Commissioner  
for Patents, Washington, D.C. 20231

Janice Di Petta  
Janice Di Petta

12-14-98  
Date

REVOCATION OF POWER OF ATTORNEYS

AND

POWER OF ATTORNEY AND CHANGE OF MAILING ADDRESS

Sir:

EMS CONTROL SYSTEMS INTERNATIONAL which is the assignee  
of record of 100% of the right, title and interest in the above-identified application (as  
evidenced by the attached Assent of Assignee to Reissue), hereby revokes all previous  
Powers of Attorney and appoints the following attorneys, all of the firm of Gray Cary  
Ware & Freidenrich, LLP, to prosecute the above-identified patent application and to  
transact all business in the Patent and Trademark Office connected therewith.

WILLIAM N. HULSEY III  
STEPHEN E. REITER  
GREGORY P. RAYMER

Registration No. 33,402  
Registration No. 31,192  
Registration No. 36,647

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103670-991260

Applicant(s): Jean Henry Albert Scholten, et al.  
Serial No.: 08/932,652  
Filed: September 18, 1997  
Page 2

PATENT  
Attorney Docket No.: CSI-1260

DAVID F. KLEINSMITH  
BARRY N. YOUNG  
TIMOTHY W. LOHSE  
STANLEY H. KIM  
DARLENE W. HAYES  
RAMSEY R. STEWART  
STEVEN R. SPRINKLE  
MICHAEL A. HOFF

Registration No. 40,050  
Registration No. 27,774  
Registration No. 35,255  
Registration No. 40,047  
Registration No. 33,899  
Registration No. 38,322  
Registration No. 40,825  
Registration No. 40,018

We acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, § 1.56(a).

Direct all telephone calls to WILLIAM N. HULSEY III at (512) 457-7040.

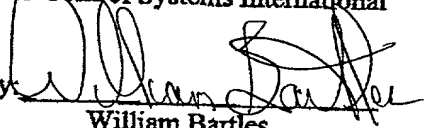
Address all correspondence to:

William N. Hulsey III  
GARY CARY WARE & FREIDENRICH, LLP  
100 Congress Avenue, Suite 1440  
Austin, Texas 78701

Respectfully submitted,

EMS Control Systems International

By

  
William Bartles

Vice President and Chief Financial Officer

Date: 1 DECEMBER 1998

Attorney Docket No.:  
019557.0121

REISSUE PATENT

Express Mail Receipt No. EM299943547US

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Reissue Application No.: \_\_\_\_\_

Reissue Applicant: EMS Control Systems International

Original Inventors: Scholten, et al.

Original Patent No.: 5,450,999

Issue Date: September 19, 1995

Title: VARIABLE SYSTEM INCLUDING ENVIRONMENTAL  
MANAGEMENT SYSTEM INCLUDING A FUZZY  
LOGIC SYSTEM

HONORABLE COMMISSIONER OF  
PATENTS AND TRADEMARKS  
WASHINGTON, D.C. 20231

Dear Sir:

ASSENT OF ASSIGNEE TO REISSUE

The undersigned, assignee of the entire interest in the  
above-mentioned letters patent, hereby assents to the  
accompanying reissue application.

Date: 17 SEPTEMBER

By:

Bill Bartles

Title: Director

PTY LTD

CSI Pacific, formerly

EMS Control Systems International PTY LTD

1625 West Crosby Road, Suite 100

Carrollton, Texas 75006

AUS01:11596.1  
019557.0121

Attorney Docket No.:  
019557.0121

REISSUE PATENT

Express Mail Receipt No. EM299943547US

## IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Reissue Application No.: \_\_\_\_\_  
Reissue Applicant: EMS Control Systems International  
Original Inventors: Scholten, et al.  
Original Patent No.: 5,450,999  
Issue Date: September 19, 1995  
Title: VARIABLE SYSTEM INCLUDING ENVIRONMENTAL  
MANAGEMENT SYSTEM INCLUDING A FUZZY  
LOGIC SYSTEM

HONORABLE COMMISSIONER OF  
PATENTS AND TRADEMARKS  
WASHINGTON, D.C. 20231

Dear Sir:

## ASSENT OF ASSIGNEE TO REISSUE

The undersigned, assignee of the entire interest in the  
above-mentioned letters patent, hereby assents to the  
accompanying reissue application.

Date: 17 SEPTEMBER

By: Bill Bartles  
Bill Bartles  
Title: Director

PTV LTD  
CSI Pacific, formerly  
EMS Control Systems International PTV LTD  
1625 West Crosby Road, Suite 100  
Carrollton, Texas 75006

AUS01:115964.1  
019557.0121

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